A STUDY OF SEVERAL ASPECTS OF TEMPERATURE AND SECCHI VISIBILITY IN INDIANA WATERS OF LAKE MICHIGAN

AN HONORS THESIS

SUBMITTED TO DR. THOMAS McCOMISH

by

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INTRODUCTION

Temperature profiles were taken at stations of depth 5, 10, 15, and 18 meters on transects near Michigan City, Burns Ditch, and Gary in Indiana waters of Lake Michigan. The study was conducted in the months of May through October in 1970 and 1971 by graduate students investigating zooplankton population dynamics under the direction of Dr. Thomas McComish. In 1972 only the Michigan City transect was studied. The profiles consisted of the temperature measured in one foot intervals from the surface to the bottom of each station. Secchi visibilty was also measured at the stations under study. The data were organized in several ways, not only to get a clearer look at the actual temperature and secchi conditions for the three years, but also to see whether any obvious changes occurred in temperature or secchi visibility over the years of the study or among stations or transects. Temperatures were also examined to see whether any changes occurred from day to night.

STUDY AREA

The area in which this study was conducted is exactly the same as that described by Johnson (1972) as follows:

Three transects were established in Indiana waters of Lake Michigan, each with stations at depths of 5, 10, 15, and 18 m (Fig. 1). The approximate distances from shore were determined for each station (Table 1).

The Michigan City transect (M) base is located 1770m (5805.6 ft) east of the point where the East Government Pier intersects with the shore. It extends from the base location into Lake Michigan on a heading of 325

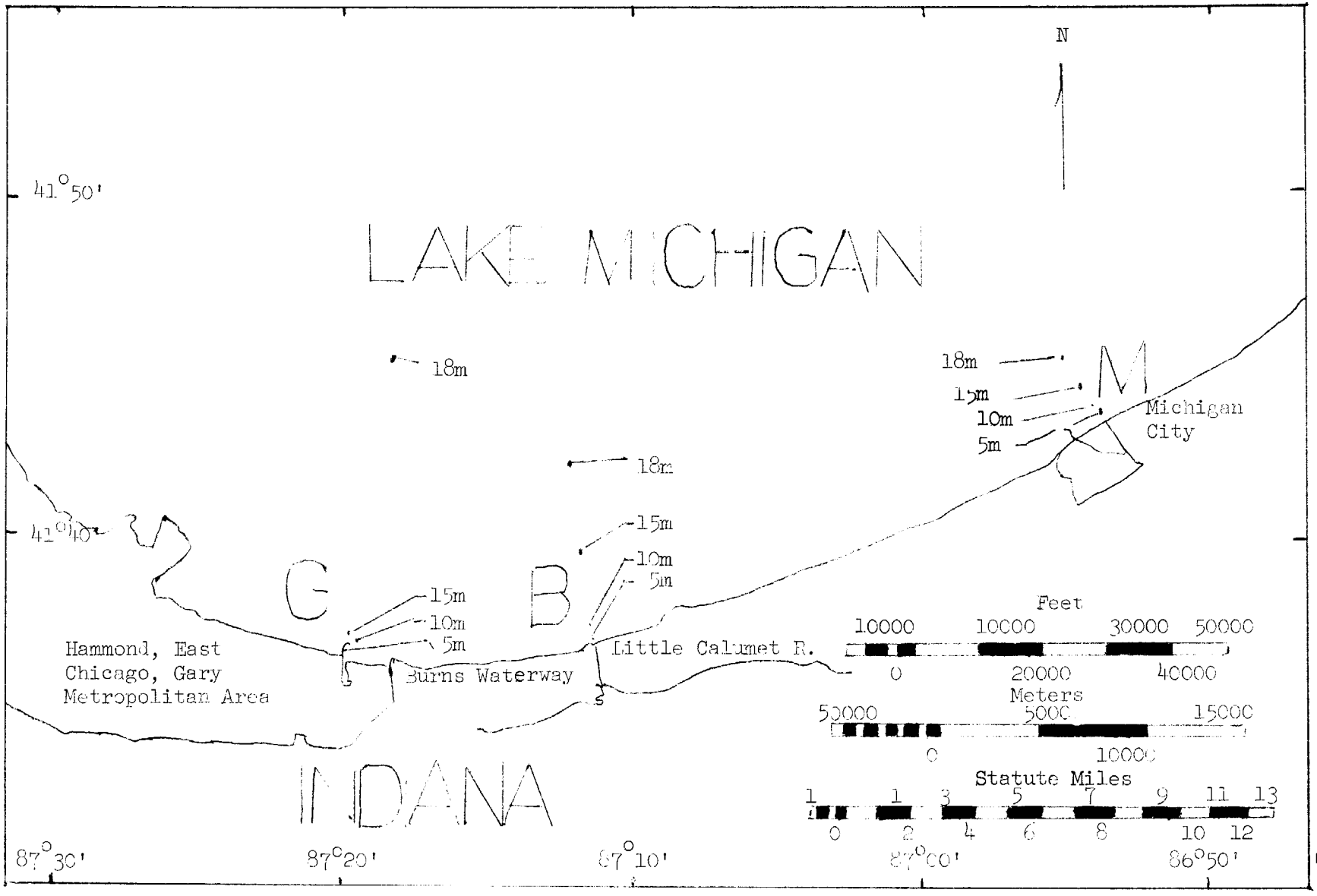

N
41°50'
LAKE MICHIGAN
18m
18m
15m
10m
5m
M
Michigan City
18m
15m
10m
5m
41°40'
G
B
15m
10m
5m
Hammond, East
Chicago, Gary
Metropolitan Area
Burns Waterway
Little Calumet R.
INDIANA
Feet
10000 10000 30000 50000
0 20000 40000
Meters
50000 5000 15000
0 10000
Statute Miles
1 1 3 5 7 9 11 13
0 2 4 6 8 10 12
87°30'
87°20'
87°10'
87°00'
86°50'

Table 1. Approximate distance of stations from the base (shore) of transects in the Indiana waters of Lake Michigan, 1970. (From Johnson, 1972)

Transect	Station/depth (m)	Distance from base (m)	Distance from base (miles)
Michigan City	5	420	0.26
	10	800	0.50
	15	2,050	1.27
	18	3,700	2.30
Burns Ditch	5	480	0.30
	10	840	0.52
	15	4,300	2.68
	18	8,700	5.40
Gary	5	320	0.20
	10	590	0.37
	15	1,020	0.64
	18	14,160	8.80

degrees. The base of the transect is on private land and the area on both sides of the transect has several scattered private homes. The nearest industry to the transect is an electric power producer, Northern Indiana Public Service Company, more than 2000 m (6560 ft) to the west near the mouth of Trail Creek.

The Burns Ditch transect (B) base is located 90 m (295.0 ft) east of the mouth of Burns Ditch in Burns Ditch Waterway. It extends into Lake Michigan on a heading of 350 degrees. The transect base is directly west of a large National Steel mill. There are various industrial and municipal inflows into the Calumet River and Burns Waterway which eventually are released into the lake through Burns Ditch.

The Gary transect (G) base is located 180 m (591.4 ft) east of the U. S. Steel Corporation canal mouth in Gary Harbor. It extends on a heading of 10 degrees. There has been extensive dredging in the harbor and the first three stations are near the shore (Fig. 1). There is heavy traffic in the harbor area.

METHODS AND MATERIALS

Temperature profile data was collected with a Yellow Springs Instrument Company Telethermometer (model 44 T D) and a Dittmore-Friemuth (model 1200) bathythermograph. Stations were located using a sounding line or a fathometer (Triton Echo-Sounder, model F-850 type A; Raytheon, model D E – 725 B) and by moving away from shore on a particular transect until the desired depth was reached. Secchi visibility was measured with a standard model Secchi disc.

RESULTS AND DISCUSSION

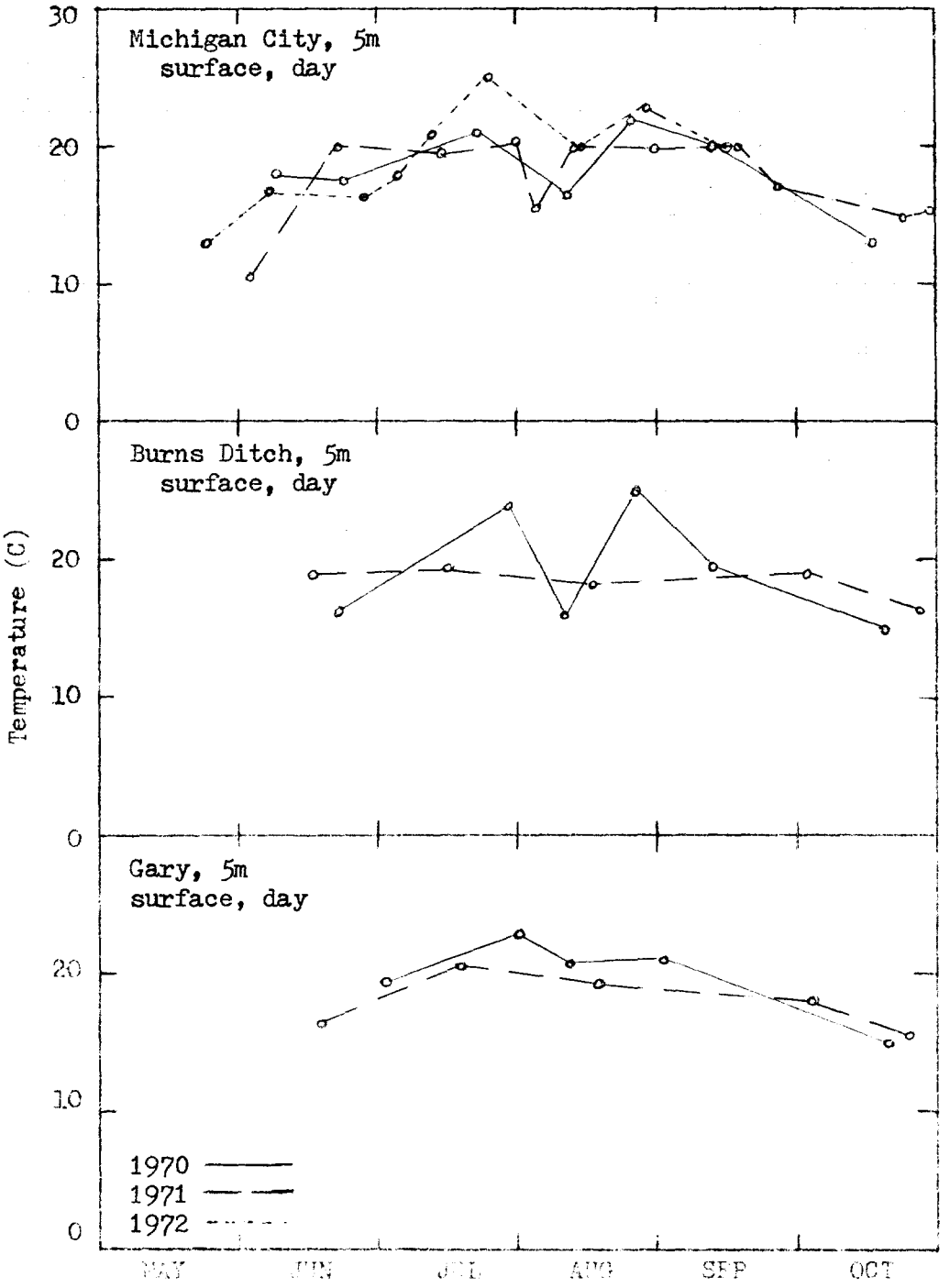
Temperature

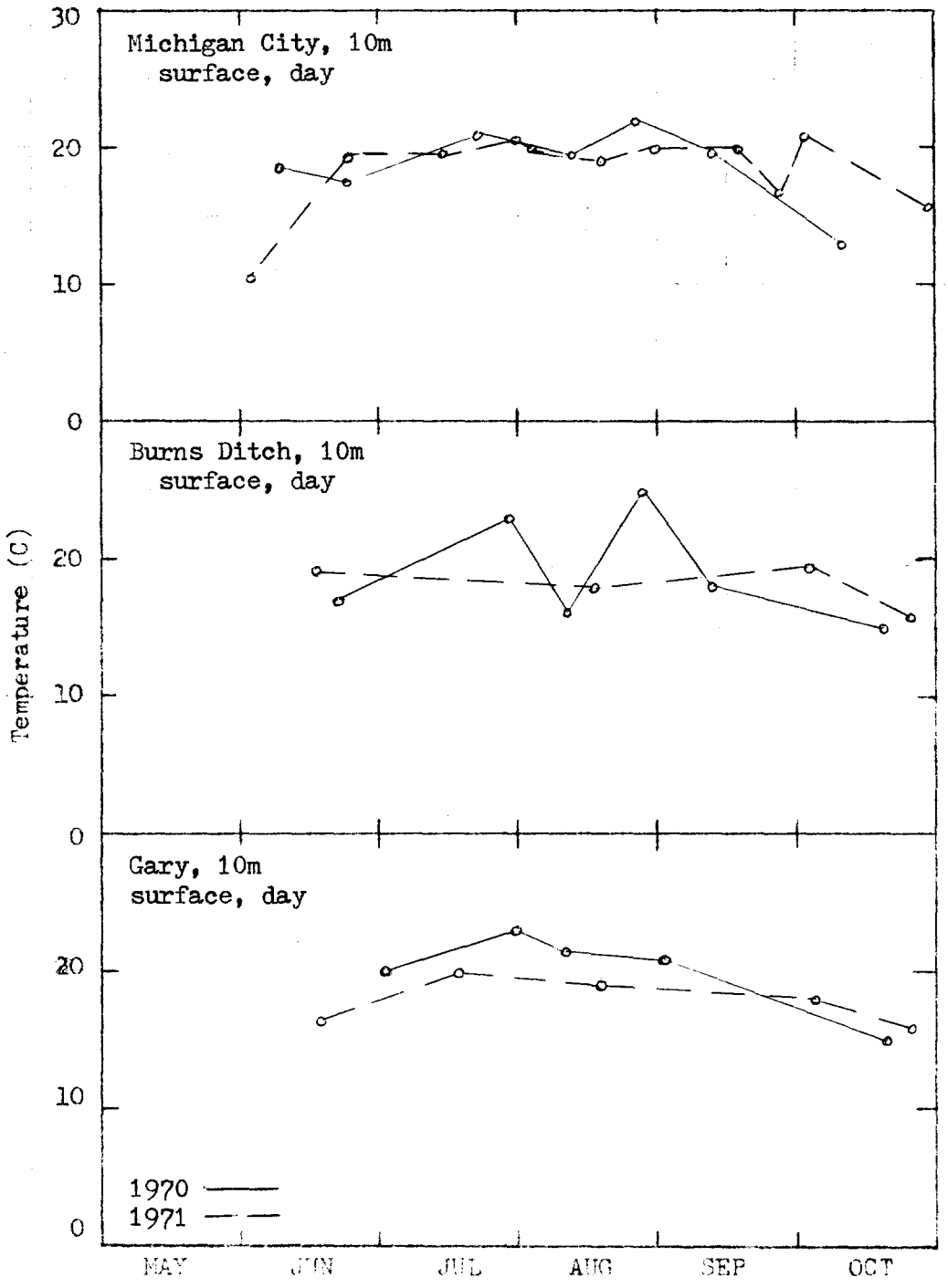
Surface Temperature

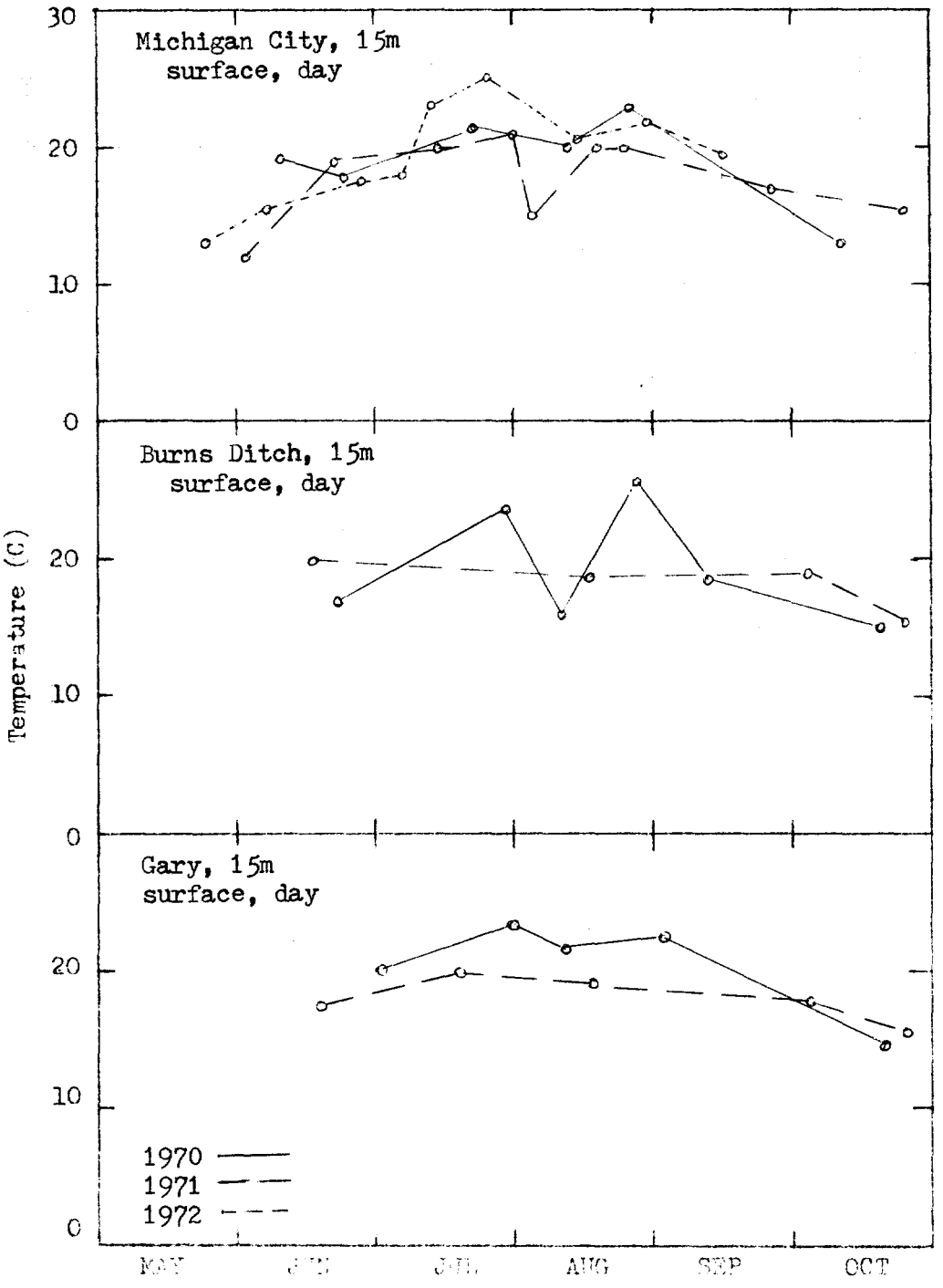
Yearly changes in surface temperature were examined at each station on the Michigan City, Burns Ditch, and Gary transects (Fig. 2 to 5). In some cases interpretation of the graphs is difficult because sampling was not done as frequently in one year as in another. The main feature which stands out, however, is that the temperature through the year is generally higher in 1970 than in 1971 at Burns Ditch and Gary. This can be seen at Burns Ditch by the fact that from early July until mid-September the temperature was as much as 7 degrees higher in 1970 than in 1971, except for the cold upwelling of 1970 (Johnson, 1972) which appeared on August 10. In addition, the maximum at Burns Ditch for 1970 of 25.5 degrees at the 15 m station is over 5 degrees higher than the maximum for 1971, which was 20 degrees and occurred on June 16.

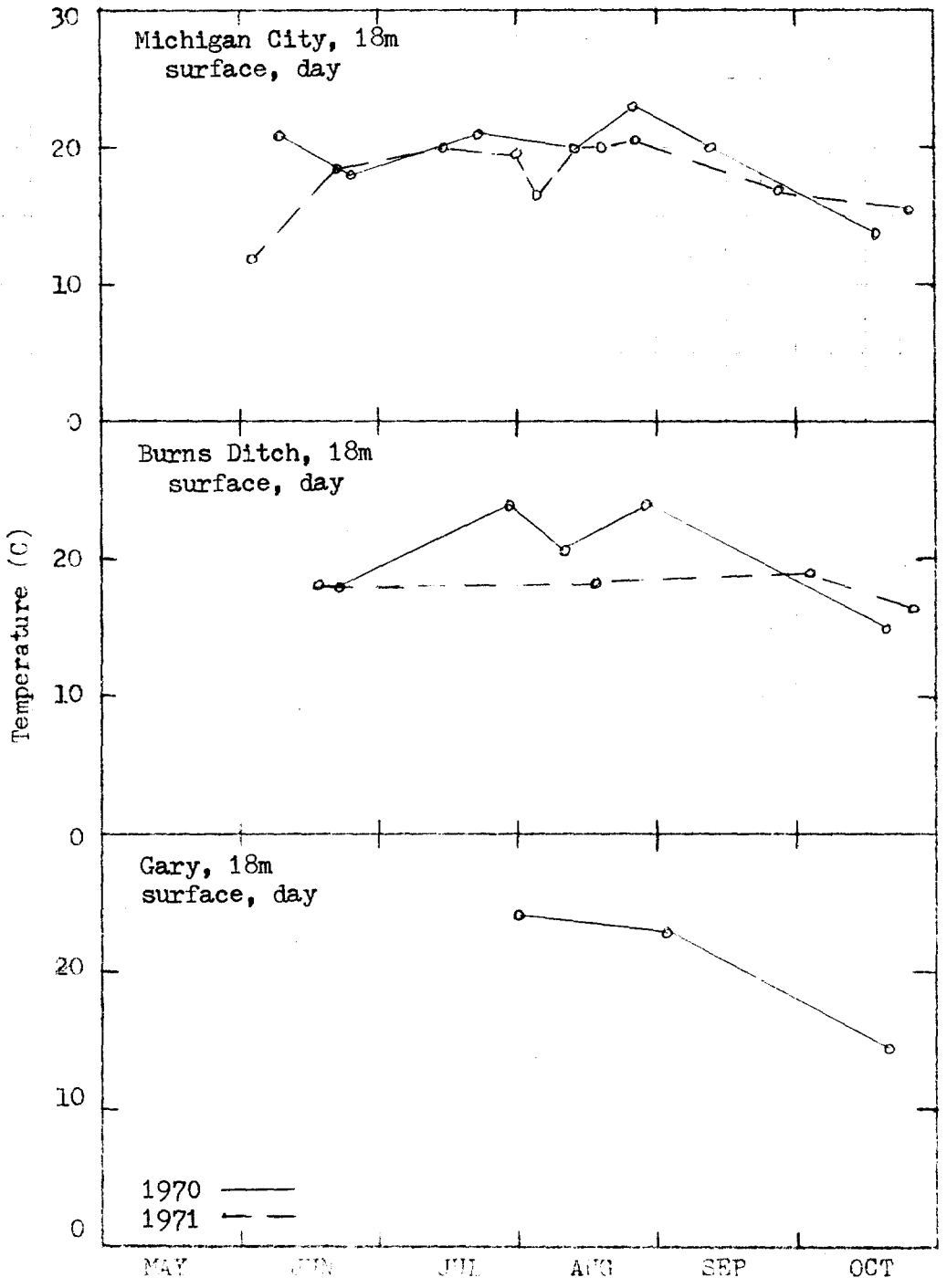
At the Gary transect the temperatures for 1970 were also above those of 1971 for most of the summer, only falling below 1971 in October. At Gary, however, the 1970 temperatures were not as far above the temperatures in 1971 as at Burns Ditch. The maximum in 1970 for Gary of 23.5 degrees on July 31 was only 3 degrees above the July 18 maximum of 1970.

At Michigan City the temperatures for 1970 and 1971 fluctuated within a few degrees of each other most of the time, although figures


Michigan City, 5m
surface, day
Burns Ditch, 5m
surface, day
Gary, 5m
surface, day
Temperature (C)
30
20
10
0
1970
1971
1972
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 10m
surface, day
Burns Ditch, 10m
surface, day
Gary, 10m
surface, day
Temperature (C)
30
20
10
0
1970
1971
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 15m
surface, day
Burns Ditch, 15m
surface, day
Gary, 15m
surface, day
Temperature (C)
30
20
10
0
1970
1971
1972
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 18m
surface, day
Burns Ditch, 18m
surface, day
Gary, 18m
surface, day
Temperature (C)
30
20
10
0
1970
1971
MAY
JUN
JUL
AUG
SEP
OCT

4 and 5 show 1970 to be a little above 1971. Temperature data for 1972 at Michigan City (Fig. 2 and 4) show that temperatures were generally higher than both 1970 and 1971, at least after early July. The maximum of 25 degrees on July 24, 1972, is higher than any maximum for 1970 or 1971 by about 3 degrees. In 1970 and 1971 temperatures did not rise to their highest level until late August, as compared to late July in 1972.

In addition to yearly changes in temperature, monthly changes in temperature can be examined from figures 2 to 5 also. For Michigan City in 1970, temperatures gradually rose through June to a peak in mid-July of 21.5 degrees, then showed a mid-summer decline on August 12 to 16.5 degrees, presumably due to the cold upwelling mentioned previously. The maximum temperature for Michigan City in 1970 of 23 degrees was recorded on August 25, after which temperatures declined through September and October.

At Burns Ditch, 1970 temperatures showed the same general pattern as Michigan City with the rise in temperature through June and July, the decline on August 10 in this case to 16 degrees, a maximum of 25.5 degrees on August 27, and a slow decline through September and October.

At Gary the amplitudes of the cold upwelling and other maxima and minima were not as great as at Michigan City and Burns Ditch, due possibly to the breakwater protection of the shallower sites and to mixing caused by ship traffic in the area or other factors (Johnson, 1972). In addition, Gary's maximum of 24 degrees on July 31 occurred before the cold upwelling and not after, as at the other two transects. After the cold upwelling, which at Gary only lowered the temperature to

20.5 degrees, temperatures declined gradually as at Michigan City and Burns Ditch through the months of September and October.

In 1971 at Michigan City temperatures rose through early June to 20 degrees and remained fairly stable through July, but on August 4 an upwelling apparently occurred, lowering temperatures. Sampling done on August 3 at the 10m station of Michigan City showed no upwelling, but the remaining three stations, which were sampled on August 4, had surface temperatures which were as much as 5 degrees lower than the 20 degrees recorded the day before. The temperatures stabilized again at around 20 degrees in late August and remained about the same through early September, then declined through the remainder of September and October.

At Burns Ditch in 1971 the temperature fluctuated only slightly through the summer from a maximum of 20 degrees on June 16 to the minimum of 15.5 in late October. The main change was the decline in October, which is normal for that time of year. No upwelling appeared as at Michigan City, but no temperatures were recorded on August 4 on this transect. The apparent stability of temperature may be due to the low number samples taken at Burns Ditch, but in any case its pattern is still roughly the same as the Michigan City pattern.

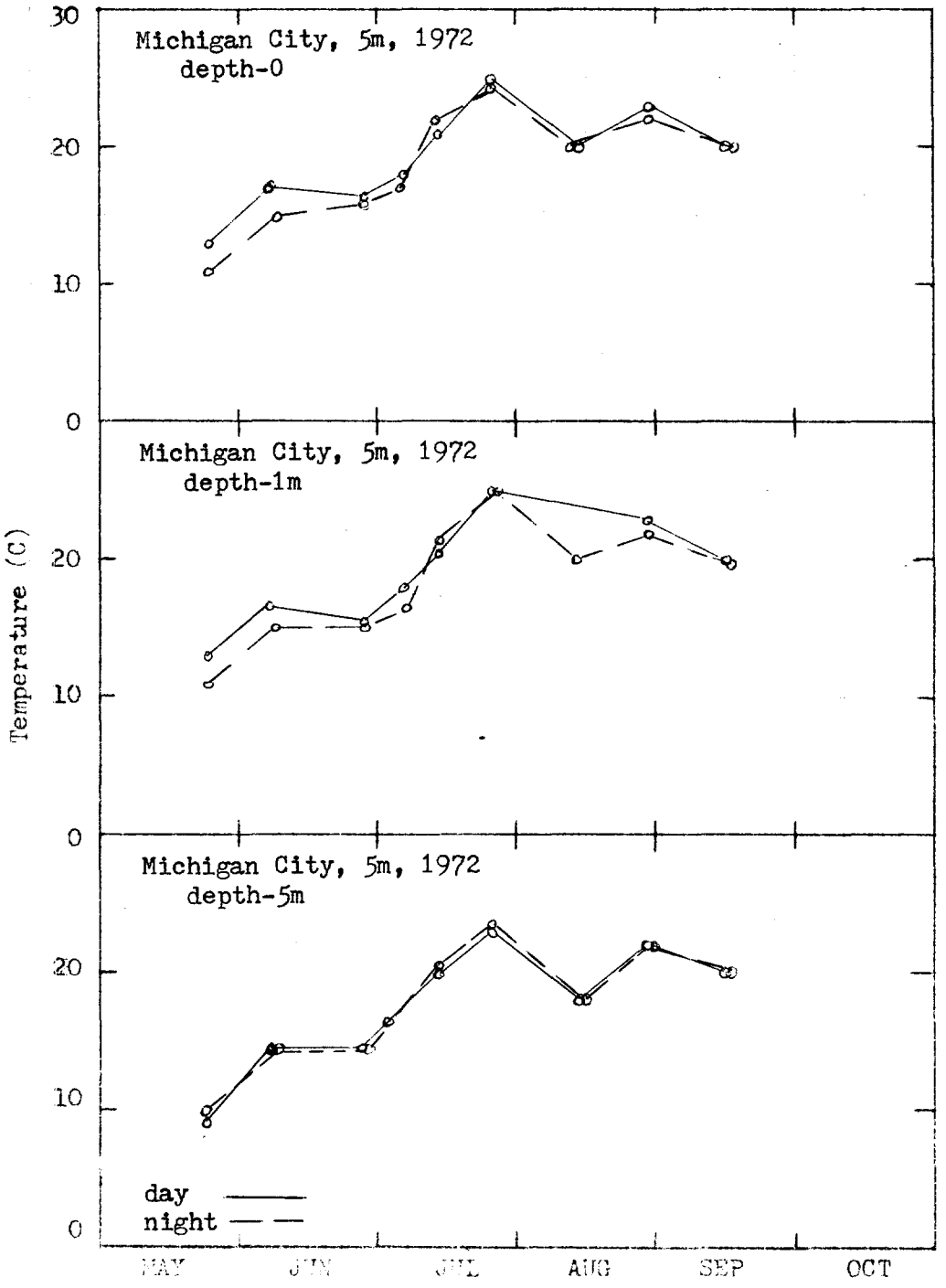
Gary showed an increase through June to a maximum of 20.5 degrees on July 18, followed by a slow decrease through August, September, and October. Again no upwelling appeared as no sampling was done on August 4, and like Burns Ditch the pattern of Gary's temperature was similar to that which occurred at Michigan City.

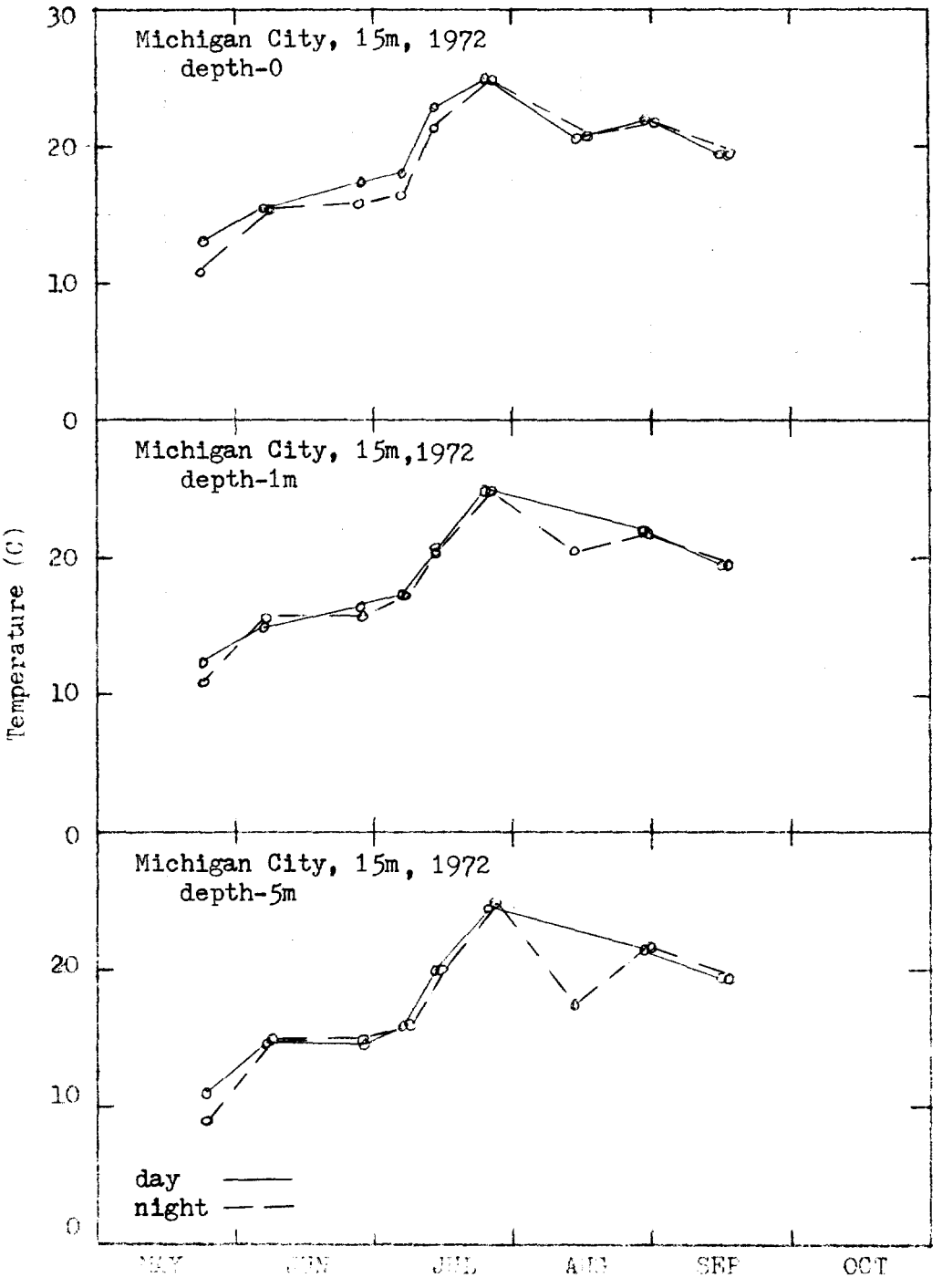
For 1972, Michigan City temperatures showed a greater range of

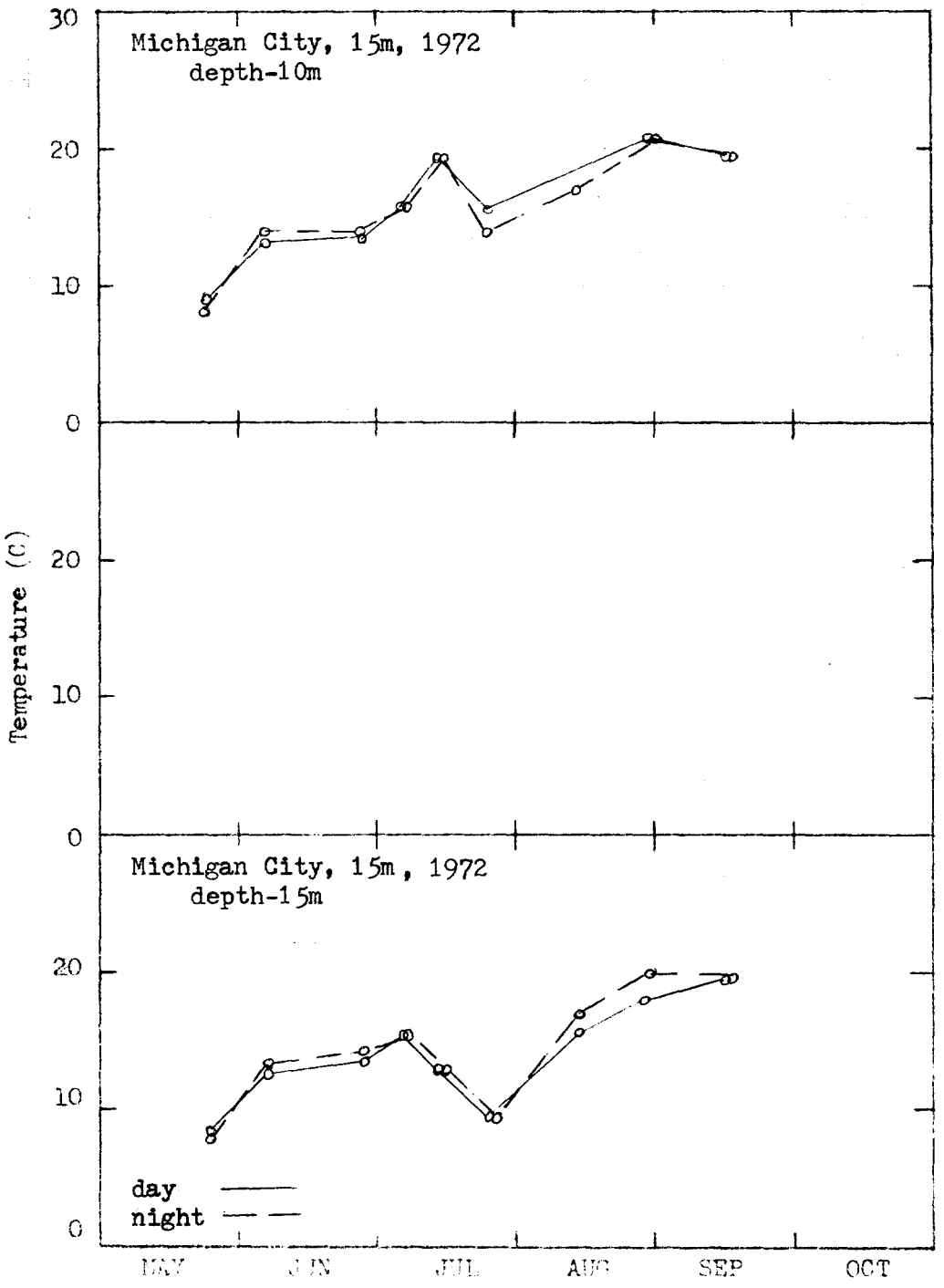
variation than any other year at any transect (Fig. 2 and 4). The minimum temperature of 13 degrees recorded on May 23 was 12 degrees less than the maximum temperature of 25 degrees, which was measured on July 24. The difference between maximum and minimum temperatures at the other two transects never rose above 10 degrees. At Michigan City in 1972, temperatures rose from late May to the late July maximum, then dropped in mid-August, only to have risen again by the end of August. In September the temperatures dropped, in accordance with the seasonal change.

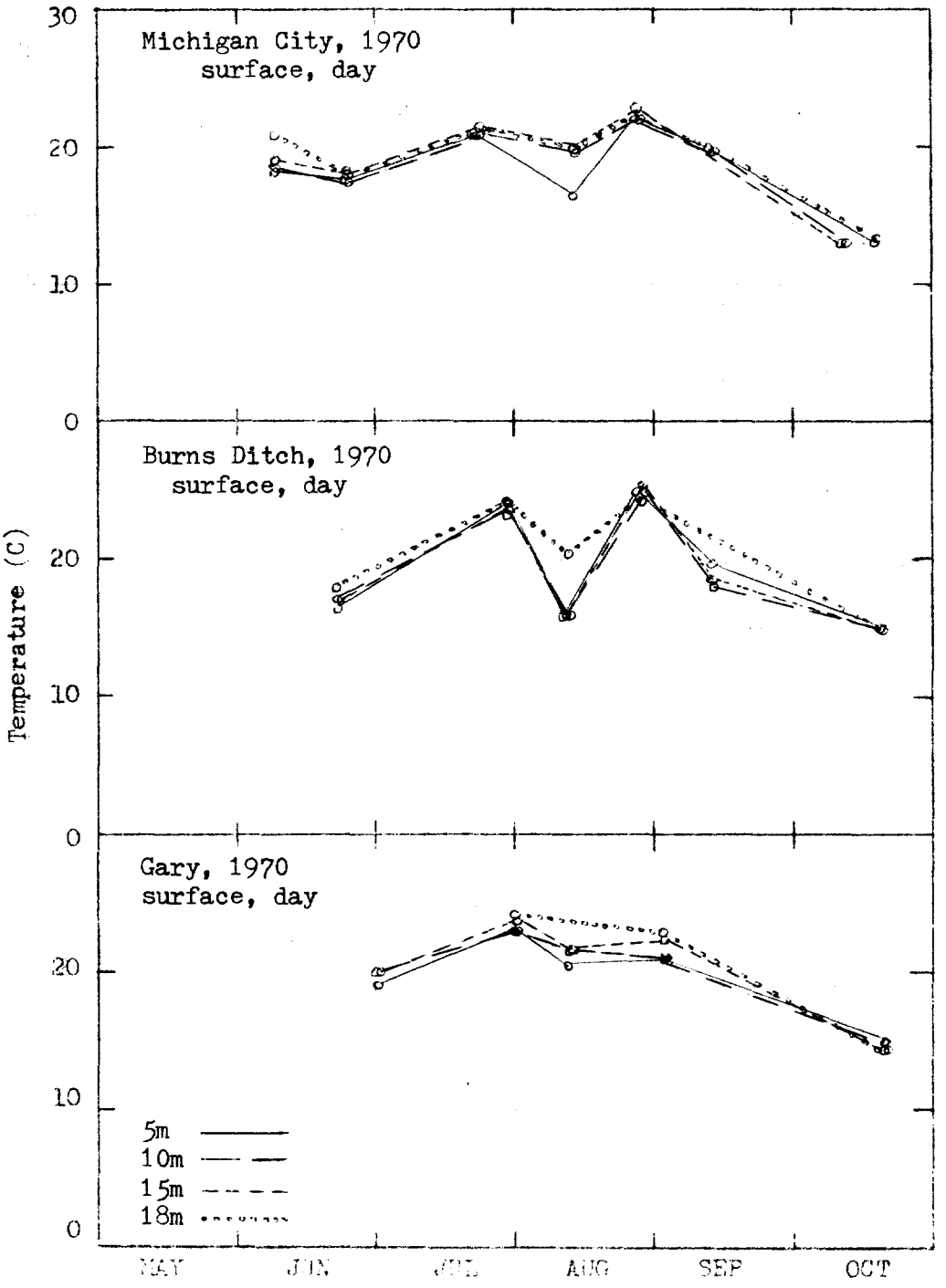
As opposed to yearly and monthly changes in temperature, figures 6 to 8 allow daily changes in surface temperature to be examined. In most cases, especially in May and June, it can be seen that the surface temperature drops 1 or 2 degrees at night from its value during the day. This would seem to indicate a cooling of the surface water in the absence of sunlight and the heat of the day. There are cases, however, where the temperature increased at night, but this was probably due to warmer water moving into the area rather than any increase in the temperature of the water itself.

Finally, surface temperatures were examined in two ways to see what differences existed at the different stations which were studied. Figure 9 shows one way in which this was done, for stations on the same transect. It is immediately evident that the surface temperatures in 1970 at the 5, 10, 15, and 18 m stations of each transect are very similar. In most cases the difference among the four stations is no more than 1 or 2 degrees. The only major difference was produced


Michigan City, 5m, 1972
depth-0
Michigan City, 5m, 1972
depth-1m
Michigan City, 5m, 1972
depth-5m
Temperature (C)
30
20
10
0
day
night
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 15m, 1972
depth-0
Michigan City, 15m,1972
depth-1m
Michigan City, 15m, 1972
depth-5m
Temperature (C)
30
20
10
0
day
night
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 15m, 1972
depth-10m
Michigan City, 15m, 1972
depth-15m
Temperature (C)
30
20
10
0
20
10
0
20
10
0
day
night
MAY
JUN
JUL
AUG
SEP
OCT

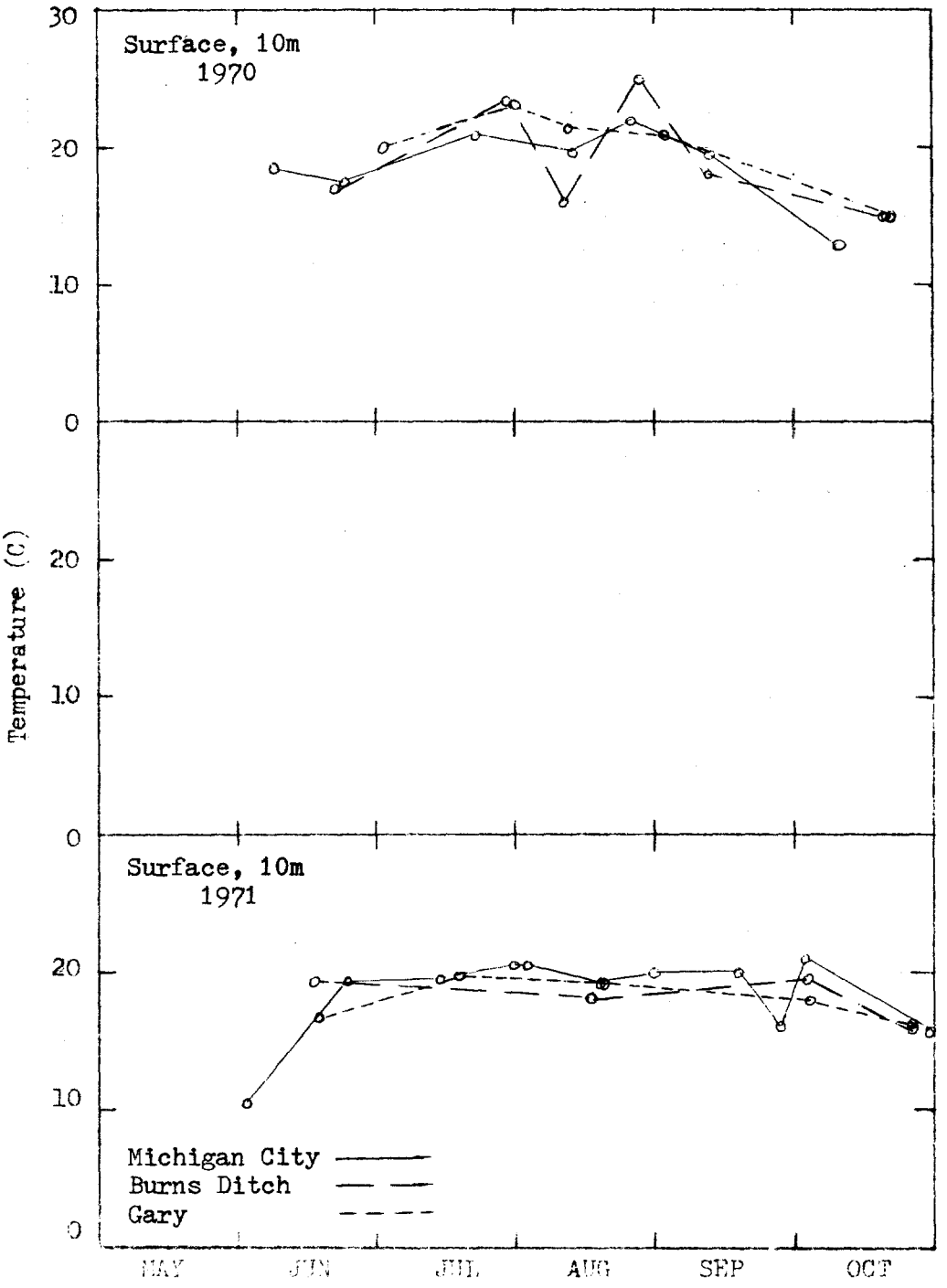

Michigan City, 1970
surface, day
Burns Ditch, 1970
surface, day
Gary, 1970
surface, day
Temperature (C)
30
20
10
0
5m
10m
15m
18m
MAY
JUN
JUL
AUG
SEP
OCT

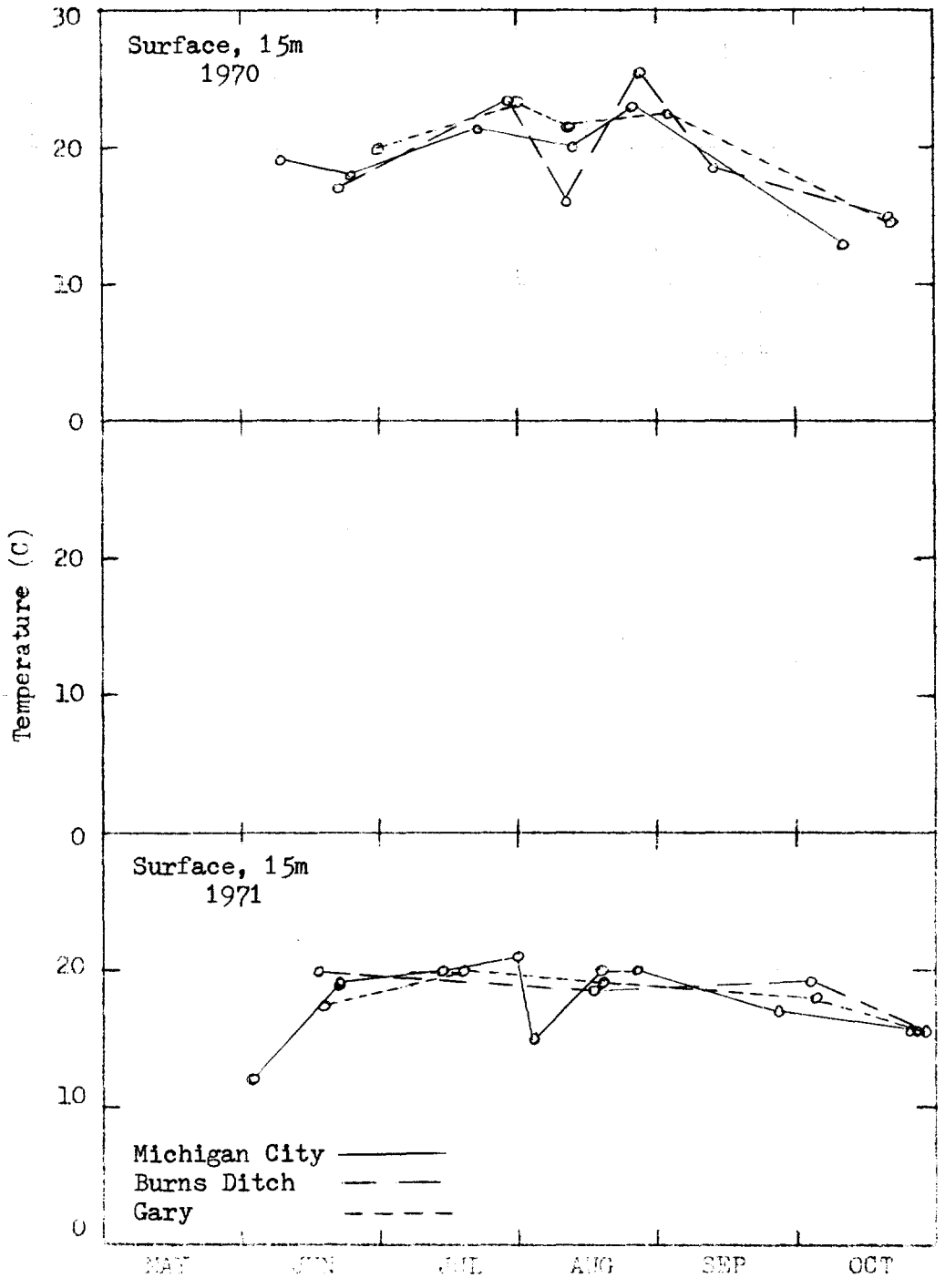
by the apparent cold upwelling on August 12. At Michigan City, it caused the surface temperature at the 5m station to be over 3 degrees cooler than the remaining 3 stations--16.5 degrees as opposed to 19.5 degrees.

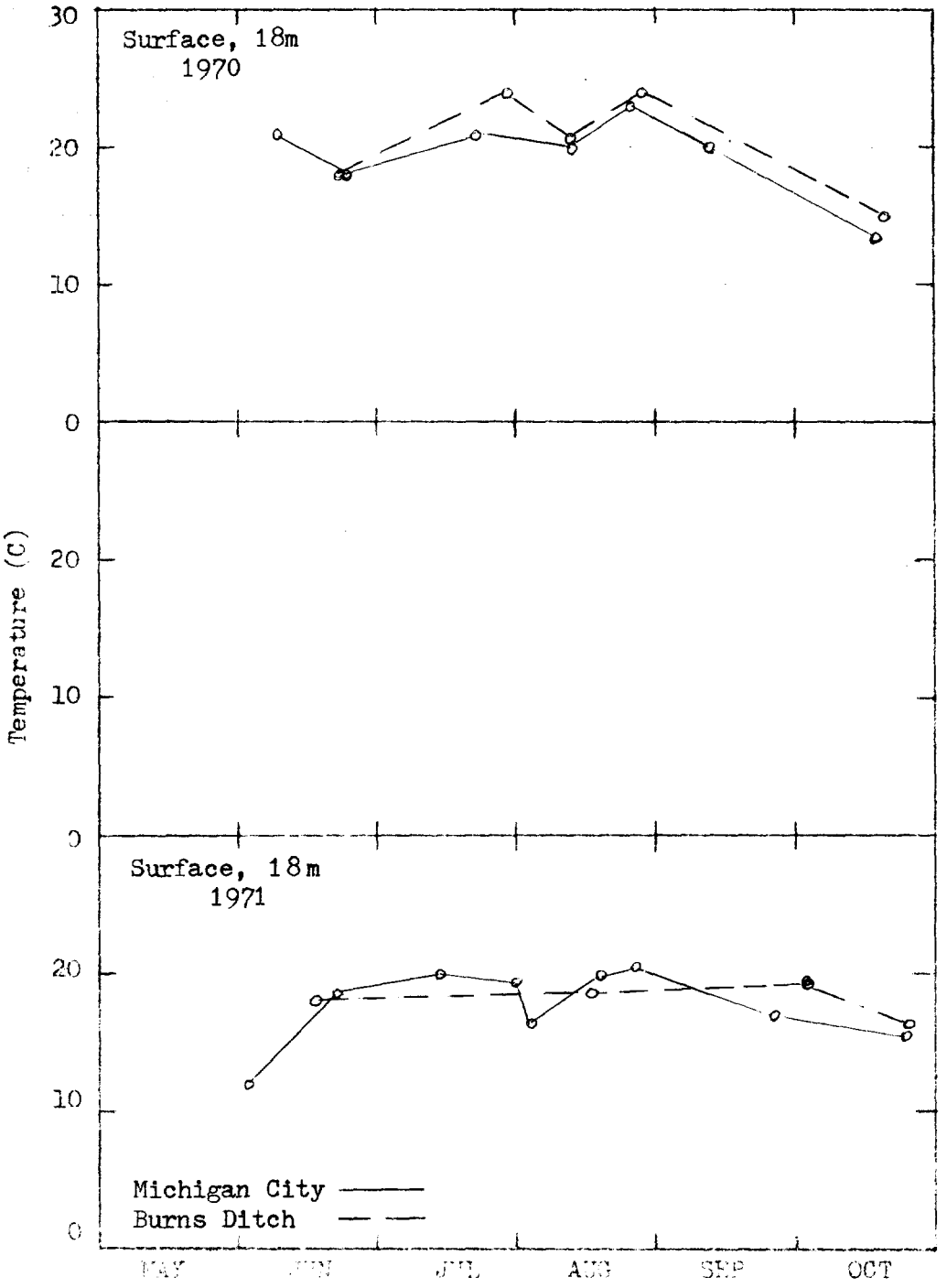
At Burns Ditch the upwelling produced a discrepancy of 4.5 degrees, with the 5, 10, and 15m stations being 16 degrees at the surface while the 18m surface temperature was 20.5 degrees. At both Michigan City and Burns Ditch, then, the upwelling had more pronounced effects at the shallower stations than at the deeper stations.

At Gary even the upwelling had no major effects on surface temperature at its stations. This is perhaps due to the previously noted fact that the stations on this transect are subject to mixing due to much lake traffic, and also to the fact that no 18m surface temperature was taken on August 12.

Stations on Lake Michigan are compared in another way by figures 10 to 13. Here the surface temperatures are compared for stations of the same depth but on different transects. For 1970 the most noticeable feature at all stations is that the Michigan City temperatures are lower than temperatures at Burns Ditch and Gary at almost all points. Gary and Burns Ditch fluctuated closely together for much of the summer, but temperatures at Burns Ditch rose a little higher than Gary in late August before the fall decline in temperatures. The only other major differences among the three transects arise because of the previously discussed upwelling which was measured on August 12. Gary dropped fewer degrees in temperature--only 2.5 degrees--due to the upwelling probably


Surface, 10m
1970
Surface, 10m
1971
Temperature (C)
30
20
10
0
20
10
0
20
10
0
Michigan City
Burns Ditch
Gary
MAY
JUN
JUL
AUG
SEP
OCT


Surface, 15m
1970
Surface, 15m
1971
Temperature (C)
30
20
10
0
20
10
0
20
10
0
Michigan City
Burns Ditch
Gary
MAY
JUN
JUL
AUG
SEP
OCT

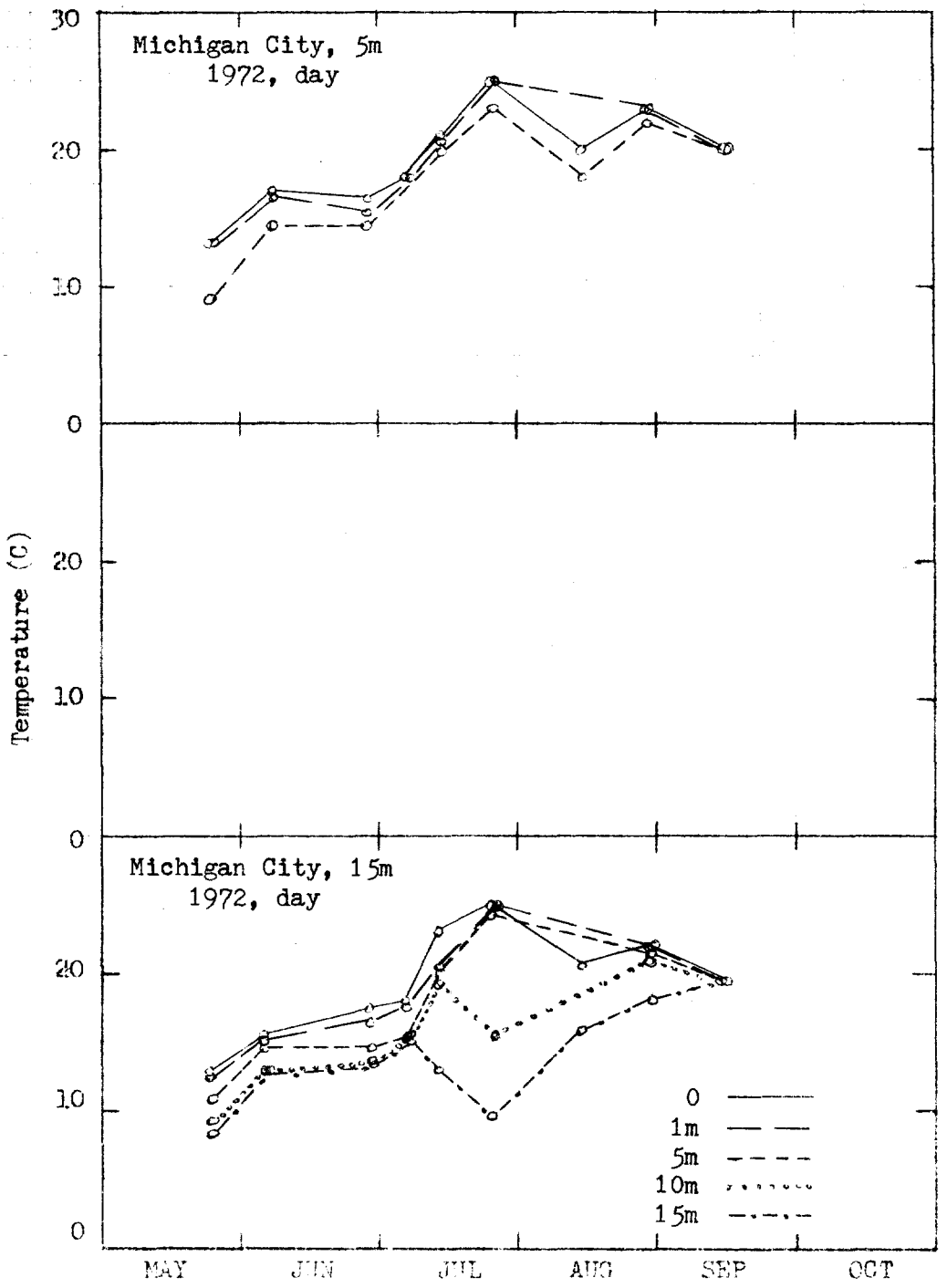

Surface, 18m
1970
Surface, 18m
1971
Temperature (C)
30
20
10
0
20
10
0
20
10
0
Michigan City
Burns Ditch
MAY
JUN
JUL
AUG
SEP
OCT

because of reasons discussed previously and because of the breakwater protection of its shallower stations. Burns Ditch showed the greatest drop--8 degrees--probably only because its temperature was highest before the upwelling. Michigan City's temperature dropped about 5 degrees from its previous value to a low of 16.5 degrees at the 5m station.

In 1971 the major feature was the similarity of surface temperatures at the three transects for stations of the same depth. The maximum temperature for the summer of 21 degrees was measured on July 30 at the 15m station on the Michigan City Transect. Temperatures on the Michigan City Transect remained very close to 20 degrees throughout the summer, while Burns Ditch and Gary temperatures were only a degree or two lower for most of the sampling period. A few sharp drops in temperature occurred at Michigan City, but the sampling was not complete enough at the other transects to allow comparison.

Temperatures below the Surface

Using data collected at the 5 and 15m stations in 1972, the temperatures at and below the surface were compared for Michigan City. Figure 14 allows a look at the monthly change in temperature below the surface through the sampling period. At the 5m station temperatures from May through August did not vary more than 3 to 4 degrees from surface to bottom. This indicates the absence of a thermocline, probably because of the stations proximity to shore and the mixing of water which occurs in the area. However, the temperatures below the surface are in all cases lower or equal to those above. This condition would


Michigan City, 5m
1972, day
Michigan City, 15m
1972, day
Temperature (C)
30
20
10
0
20
10
0
20
10
0
0
1m
5m
10m
15m
MAY
JUN
JUL
AUG
SEP
OCT

be normal as the higher density of the cooler water would cause it to remain below the warmer water above. On September 15 the temperature at all depths was 20 degrees at the 5m station, indicating that the fall overturn had occurred and homothermy was present.

At the 15m station the bottom temperatures were also 4 to 5 degrees below the surface temperatures until early July. On July 13, however, the temperature was 6.5 degrees lower at a depth of 15 m than it was at 10 m down, thus indicating the establishment of a thermocline or temperature stratification, by definition. On July 24, the thermocline extended from 5 m below the surface all the way to the bottom. By the end of August, however, the thermocline no longer existed and homothermy was found at the 15m station on September 15, indicating that the fall overturn had occurred. In contrast to the 5m station, then, it seems that the 15m station was deep enough to allow temperature stratification to take place.

Sub-surface temperatures can also be examined for daily variations by returning to figures 6 to 8. It is obvious that the variation from day to night is very slight, especially at the deeper depths. The maximum drop in temperature at night occurred at 1m under the surface at the 5m station, and that was a drop of only 2 degrees. In most cases, then, there was very little change, if any. At a depth of 5 m on the 5m station the maximum change was 1 degree on May 23. The rest of the year showed a change of 0.5 degrees or no change at all.

At the 15m station, again, very little change occurred in sub-surface temperatures and when there was a drop it was usually only of

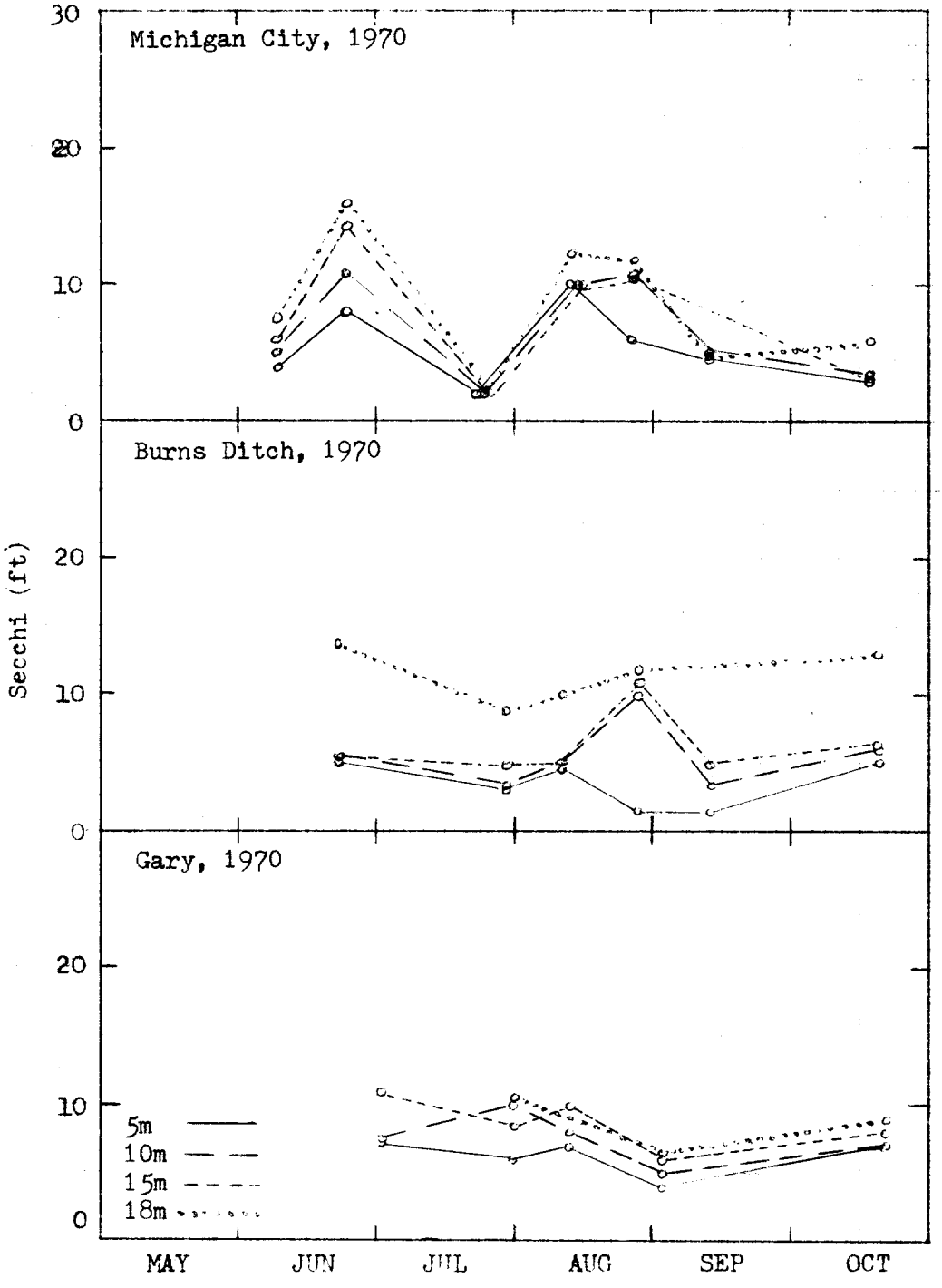
0.5 to 1 degree. This indicates that temperatures do change slightly from day to night, but the greatest change occurs on or near the surface. At 5 or 10 m down, it seems, very little change occurs.

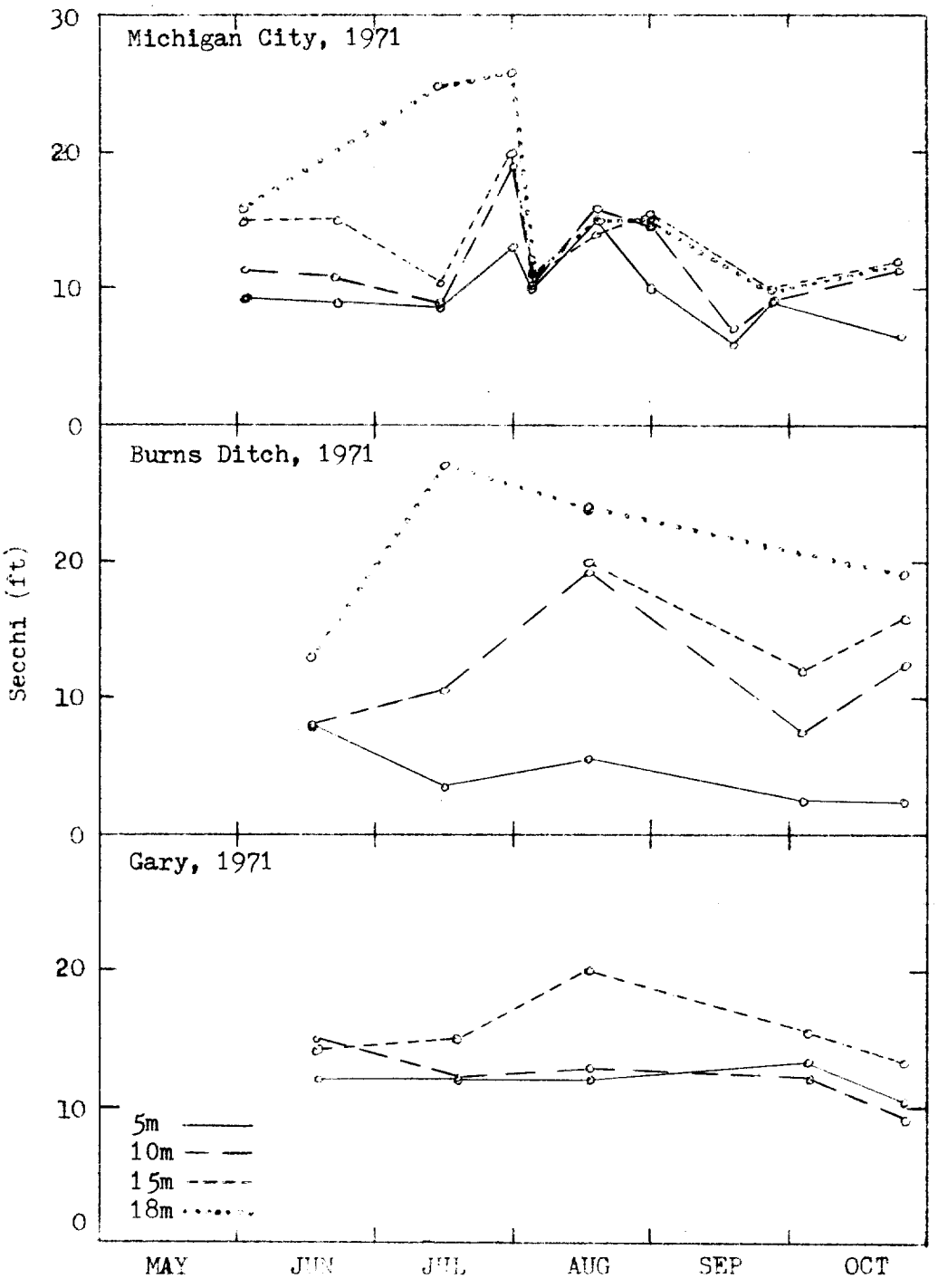
SECCHI VISIBILITY

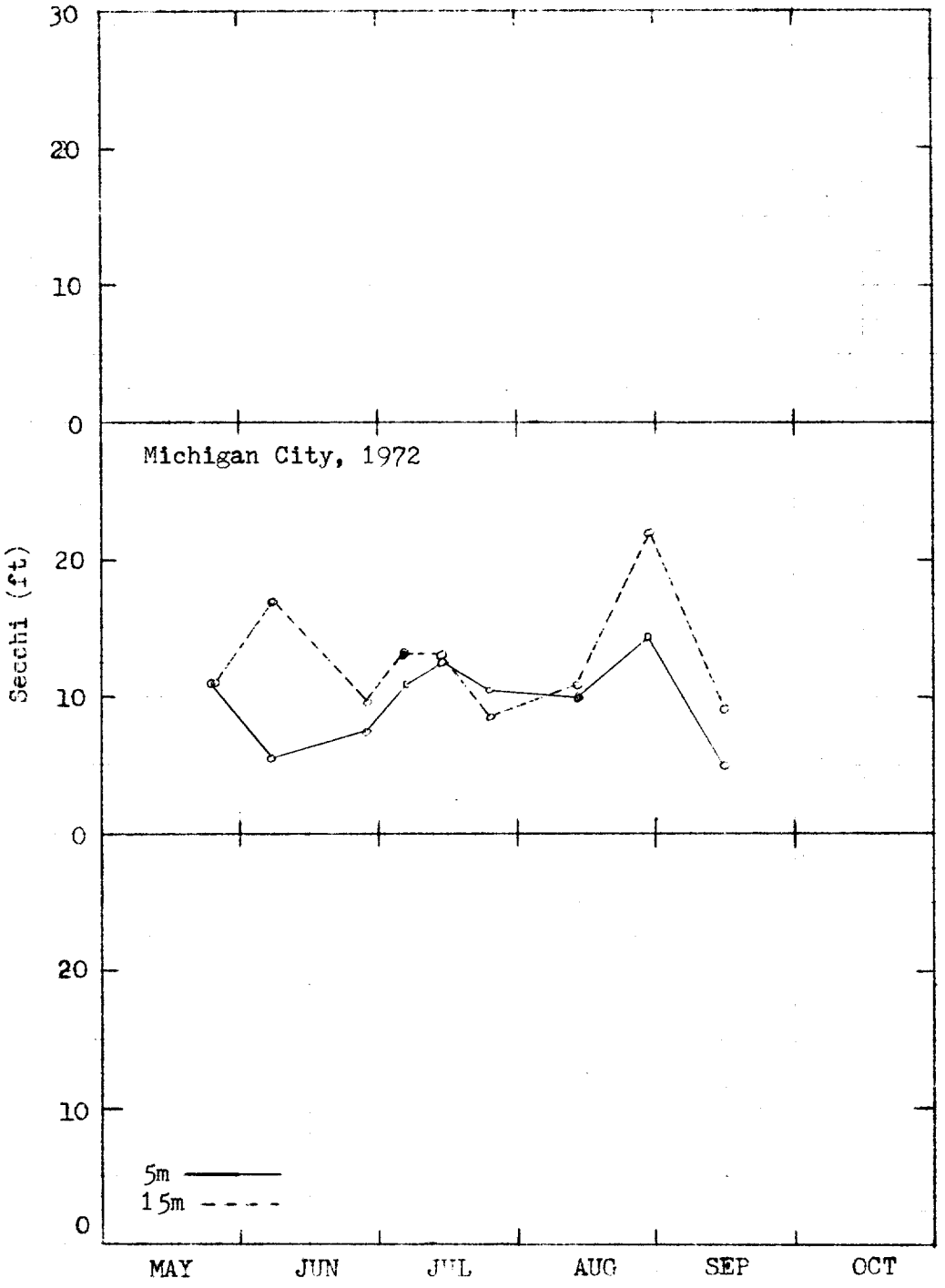
Station Differences

The secchi visibility of stations on the same transect is examined on figures 15 to 17. For 1970 at Michigan City the maximum secchi reading of 16 feet occurred at the 18m station on June 23. The graphs at all three transects generally show that the secchi readings increased with increased depth of station and distance from shore. On July 22 the secchi visibility took a sharp drop to 2 feet at all stations on the Michigan City Transect. This would most likely be due to bad weather or some internal change in the lake such as a seiche. At mid-August the secchi visibility was found to be at normal levels again. For the remainder of the year the secchi was rather erratic, but basically it tended to decline as fall approached.

At Burns Ditch in 1970 the maximum secchi reading was also taken at the 18m station, on June 22. Here the 18m station at times had a secchi visibility almost 9 feet more than even the 15m station, and at no time was its value below any of the other stations. The 5, 10, and 15m stations had very similar secchi readings until mid-August, after which the 5m station's visibility decreased to 1.5 feet and all the other stations increased. The 1.5 foot reading was the minimum for Burns Ditch in 1970.


Michigan City, 1970
Burns Ditch, 1970
Gary, 1970
Secchi (ft)
30
20
10
0
5m
10m
15m
18m
MAY
JUN
JUL
AUG
SEP
OCT


Michigan City, 1971
Burns Ditch, 1971
Gary, 1971
Secchi (ft)
30
20
10
0
5m
10m
15m
18m
MAY
JUN
JUL
AUG
SEP
OCT


30
20
10
0
Michigan City, 1972
Secchi (ft)
20
10
0
20
10
0
5m
15m
MAY
JUN
JUL
AUG
SEP
OCT

At Gary there was very little change in secchi among the four stations. Although the 18m secchi reading was usually higher than the other stations, the difference was only 2 to 3 feet at most. The maximum for Gary in 1970 was 11 feet at the 15m station on July 1. The minimum of 4 feet came on September 2 at the 5m station.

For 1971 the range of secchi variation was much greater than in 1970. At Michigan City the maximum secchi reading was 26 feet and occurred on July 30 at the 18m station. This was 13 feet more than the secchi visibility at the 5m station on the same day. The minimum secchi reading of 6 feet occurred on September 18 at the 5m station. One very interesting feature is the lowering of secchi readings at all stations to 10 feet which occurred on August 4. This corresponds exactly with the apparent upwelling which lowered temperatures on August 4 at Michigan City. It looks as if the upwelling caused an increase in turbidity as well as a decrease in temperature.

At Burns Ditch there is also a wide separation of secchi values in 1971. The maximum reading for the summer of 27 feet which occurred on July 15 at the 18m station is over 24 feet more than the minimum value, which came on October 25 at the 5m station. At Burns Ditch the increase in secchi visibility which occurs with greater depth of station and distance from shore is very noticeable (Fig. 16).

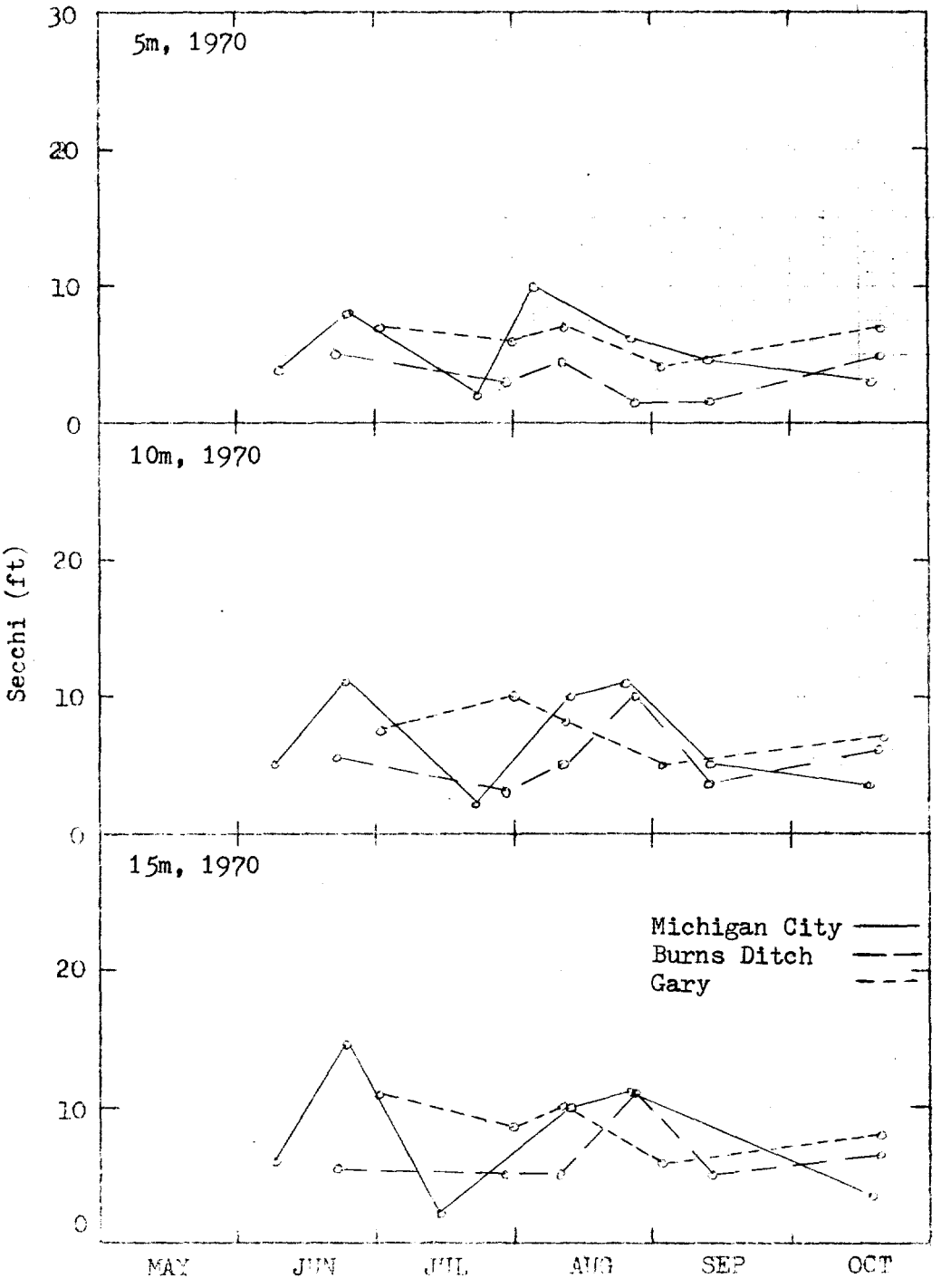
Secchi readings at Gary in 1971 show little variation, especially between the 5 and 10m stations. This may be due to the very close proximity of these stations to one another (Table 1). The 15m station shows somewhat higher visibility, and the maximum of 25 feet was

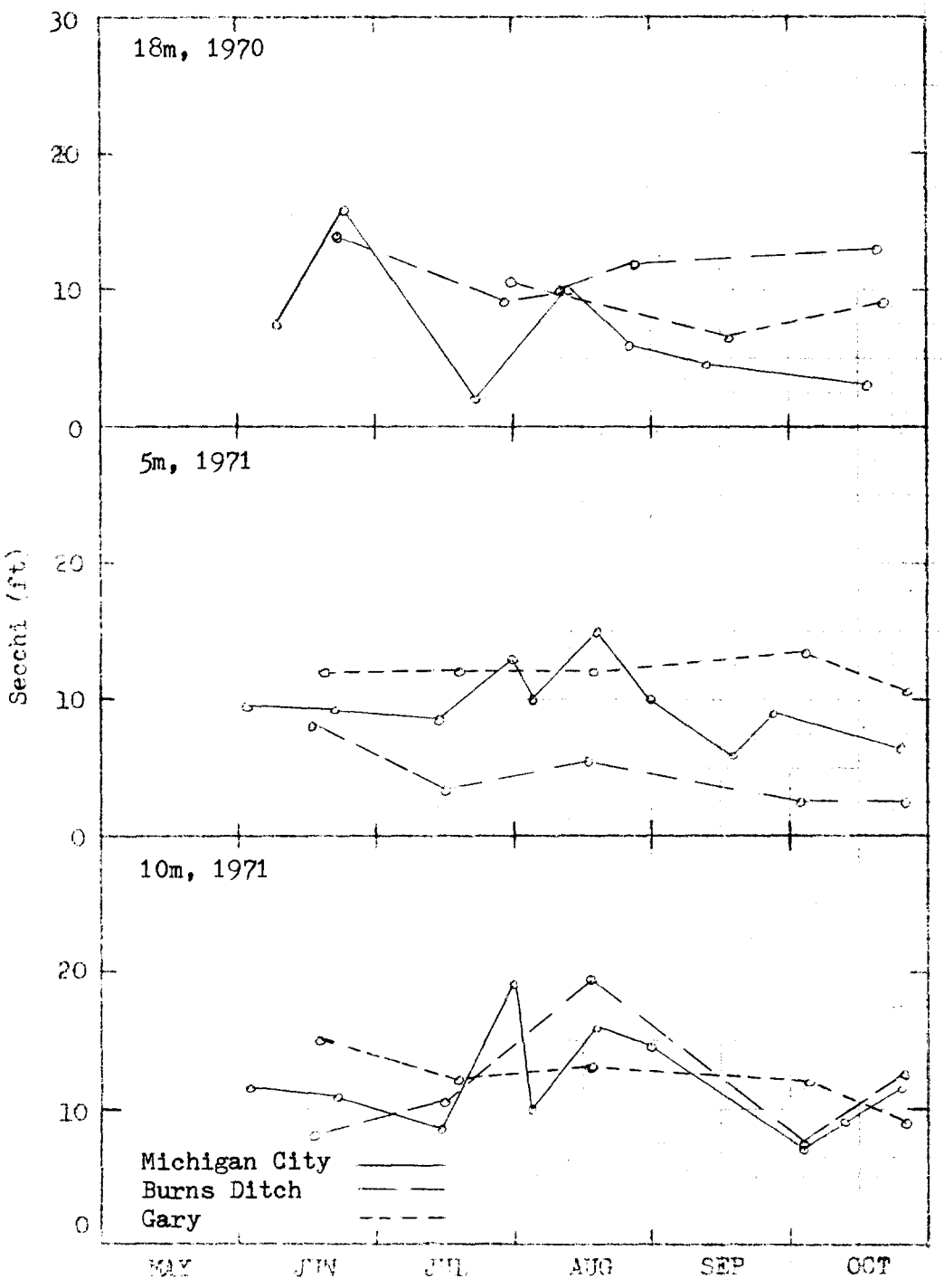
recorded here on August 17.

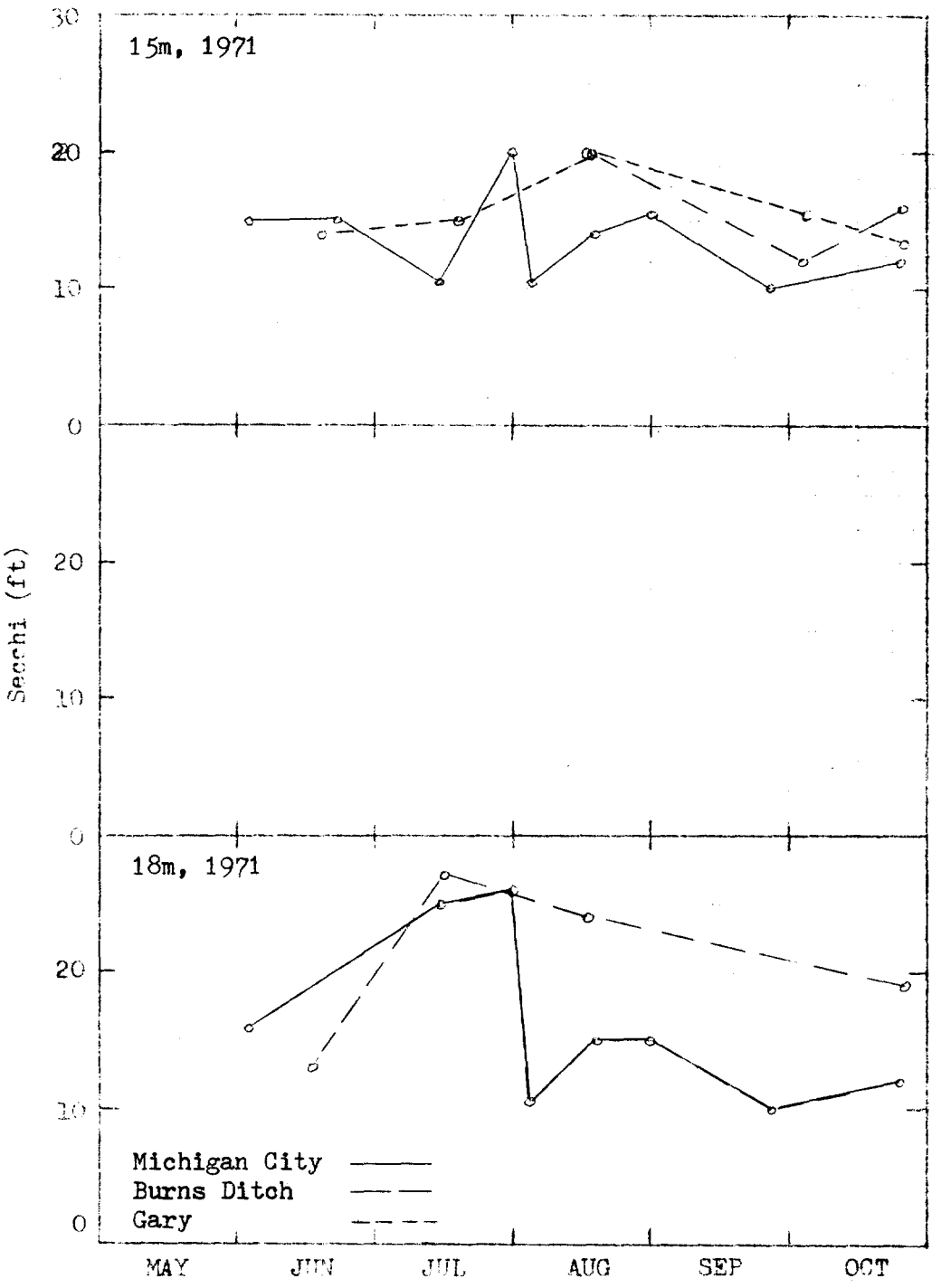
At Michigan City in 1972 (Fig. 17) the 5 and 15m stations are examined. The maximum secchi value occurred, as usual, at the deeper station. This was a reading of 22 feet on August 28. The minimum of 5 feet was recorded on September 15 at the 5m station. From July through August secchi visibility was very similar at the two stations, but at the beginning and end of the summer the two were separated by as much as 10 feet.

Figures 18 to 20 compare the secchi visibility at stations of the same depth but on different transects. For 1970, the 5m stations show considerable similarity. Secchi values at Burns Ditch were the lowest, ranging from 1.5 to 5 feet. Gary followed the same pattern of peaks and depressions (Fig. 18), but at a range of from 4 to 7 feet. Michigan City, however, did not follow the same pattern and also fluctuated more than Burns Ditch and Gary over the sampling period, with a difference of 8 feet from its maximum to its minimum readings. At the 5m stations for 1970 the maximum visibility attained at any transect was 10 feet, and it occurred at Michigan City. The minimum was 1.5 feet at Burns Ditch.

For the 10m stations in 1970 there was considerably more variation over the sampling period; that is, there were more changes from high to low visibility over the year. Michigan City had the greatest range in values, as it did at the 5m stations. This time its maximum of 11 feet on June 23 was the highest for all three transects and its low of 2 feet was the minimum for all transects. This gave Michigan City a range in values of 9 feet, while the range of Burns Ditch was only 6.5


5m, 1970
10m, 1970
15m, 1970
Secchi (ft)
30
20
10
0
MAY
JUN
JUL
AUG
SEP
OCT
Michigan City
Burns Ditch
Gary


18m, 1970
5m, 1971
10m, 1971
Secchi (ft)
30
20
10
0
Michigan City
Burns Ditch
Gary
MAY
JUN
JUL
AUG
SEP
OCT


15m, 1971
18m, 1971
Secchi (ft)
30
20
10
0
20
10
0
20
10
0
Michigan City
Burns Ditch
Gary
MAY
JUN
JUL
AUG
SEP
OCT

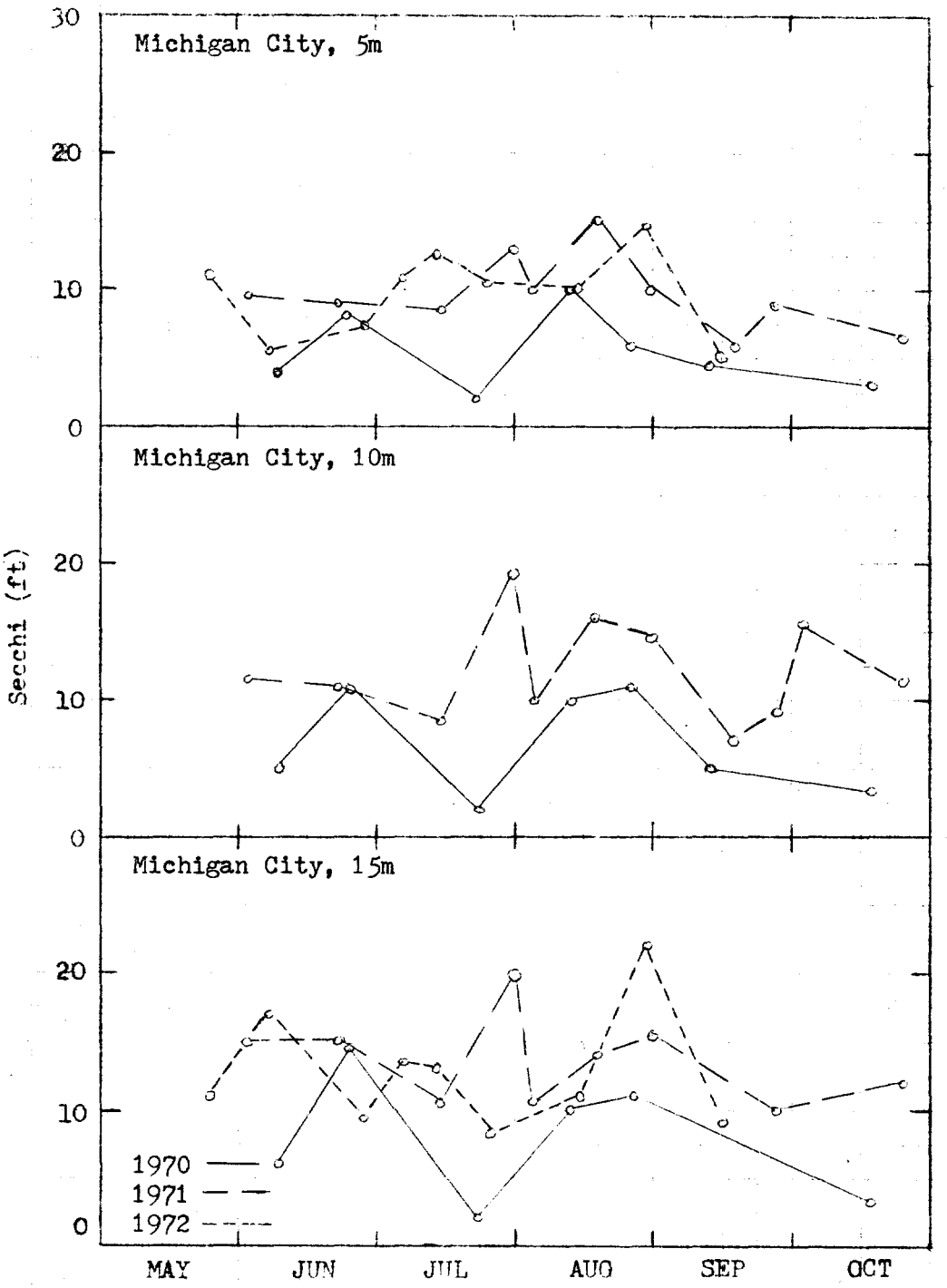
feet, and Gary's 5 feet.

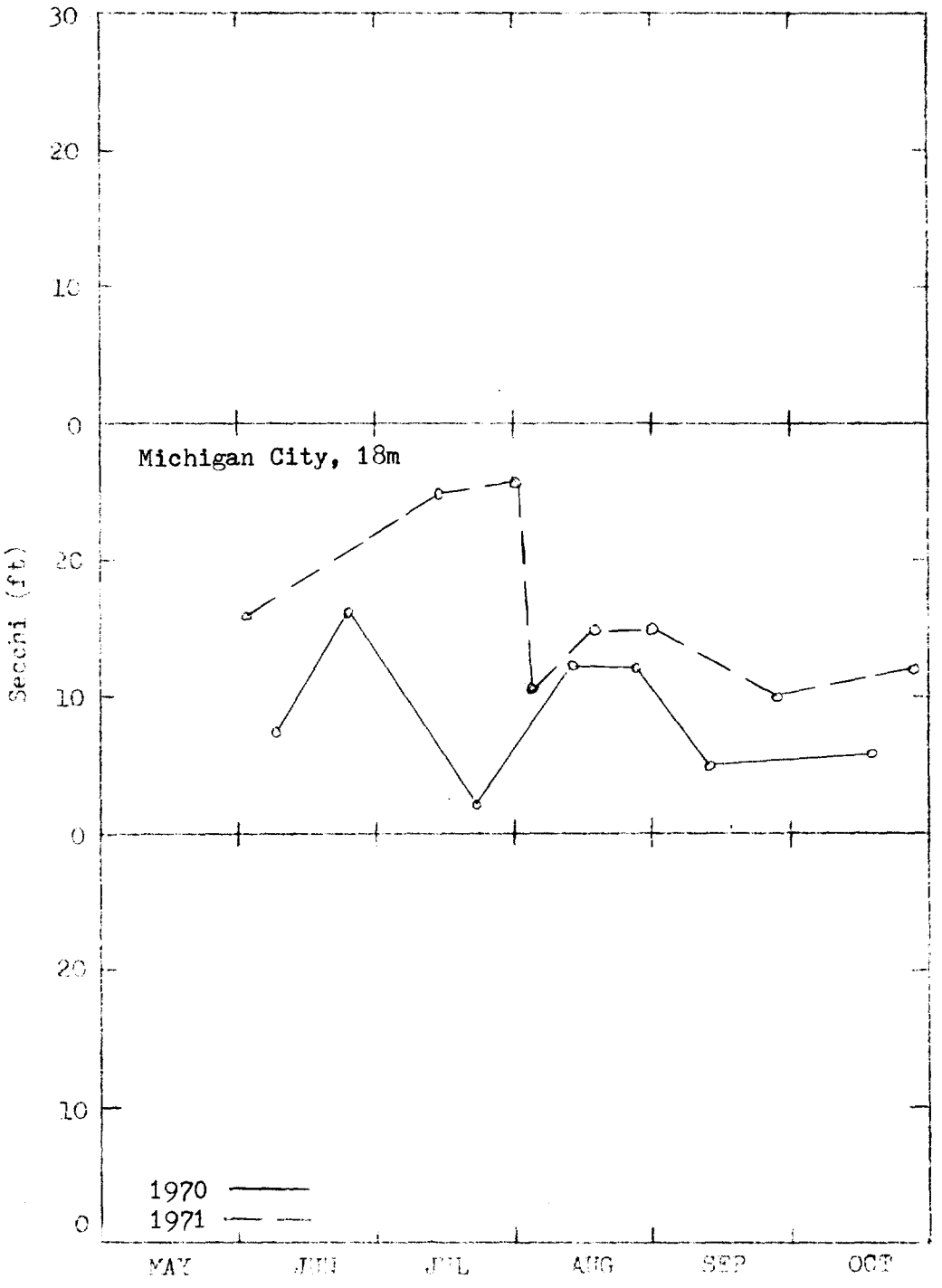
The 15 and 18m stations for 1970 were very similar to the 10m station. At both stations there was more fluctuation at Michigan City than at Burns Ditch and Gary, and at at both stations Michigan City had the maximum and minimum secchi values for the three transects. It is difficult to pinpoint the stations of one transect as having a lower or higher secchi visibility than the stations on another transect since the readings fluctuate so much. However, the 18m station at Michigan City in 1970 (Fig. 19) seems to be lower in visibility than the 18m stations at Burns Ditch and Gary for most of the summer.

For 1971 the secchi visibility of the 5m stations on the three transects are fairly stable. Gary has the highest values for most of the summer and is very consistent with secchi visibilities between 13.5 and 10.5 feet. Michigan City had the maximum value for a 5m station at 15 feet, but in general it stayed in the 5 to 10 foot range. Burns Ditch had the lowest secchi readings, mostly between 5 and 2.5 feet, but its reading at mid-June was 8 feet.

At 10m the most noticeable features are the usual stability of readings at Gary, and the drop on August 4 at Michigan City discussed previously in connection with the upwelling. At Burns Ditch August 16 saw the maximum secchi value for 10m stations of 19 feet, while the minimum of 7 feet came at Michigan City on September 18.

The 15 and 18m stations show again the drop in secchi at Michigan City on August 4, and also that the Michigan City visibility is generally lower than that at Burns Ditch and Gary. Aside from these things


Michigan City, 5m
Michigan City, 10m
Michigan City, 15m
Secchi (ft)
30
20
10
0
1970
1971
1972
MAY
JUN
JUL
AUG
SEP
OCT


30
20
10
0
Michigan City, 18m
Secchi (ft)
20
10
0
20
10
0
1970
1971
MAY
JUN
JUL
AUG
SEP
OCT

SUMMARY AND CONCLUSIONS

Temperature profiles were taken and secchi visibility measured from May through October in 1970, 1971, and 1972 at depths of 5, 10, 15, and 18m on transects into the Indiana waters of Lake Michigan from points near Michigan City, Burns Ditch, and Gary. The following conclusions have been drawn from graphs of several aspects of the data.

1. Surface temperatures were generally higher in 1970 at Burns Ditch and Gary than in 1971. For Michigan City 1970 and 1971 were fairly similar, but 1972 temperatures were higher than both 1970 and 1971.

2. Monthly changes in surface temperature for Michigan City Burns Ditch and Gary indicate the presence of upwellings on August 10, 1970 and August 4, 1971. Generally, temperatures rose through mid-summer and declined as fall approached. In 1972 Michigan City temperatures followed this pattern also.

3. Daily changes in surface temperature indicate that temperatures normally declined from 1 to 2 degrees at night at Michigan City.

4. Surface temperatures were very similar at the four stations on one transect in the year examined (1970).

5. For stations of the same depth but on different transects, Michigan City was lower in surface temperature than Burns Ditch and Gary in 1970. In 1971 the three transects were similar in surface temperature, but with Michigan City again being a little lower especially at the deeper stations.

6. Temperatures below the surface at the 5m station of Michigan

City in 1972 showed a gradual cooling to the bottom for the entire summer. At the 15m station, however, the water was deep enough to allow a thermocline to develop.

7. Sub-surface temperatures did not lower more than 0.5 to 1 degree at night from their daytime values, except for depths near the surface

8. Secchi visibility was highest in all years for the stations farthest from shore and deepest at all three transects.

9. For 1970 Gary appeared to have a higher secchi visibility than Burns Ditch, and Michigan City fluctuated too much to allow a generalization. In 1971 Michigan City showed the lowest secchi visibility at most stations, with Gary above Burns Ditch in most cases.

10. At Michigan City secchi visibility in 1970 was lower than 1971 and 1972. For 1971 and 1972 the secchi visibility was very similar.

LITERATURE CITED

Johnson, D. L. 1972. Zooplankton Population Dynamics In Indiana Waters of Lake Michigan in 1970. Master's Thesis. Ball State Univ. 1-56.

Appendix 1. Daytime temperatures (C) in Lake Michigan on the Michigan City Transect at 5, 10, 15 and 18 m stations by depth in 1970.

Station / Date	Depth (m) 0*	1	2	3	4	5	7	10	12	15	18
5m											
Jun 8	18.0	16.5	16.5	16.0	16.0	16.0					
Jun 23	17.5	17.0	16.0	16.0	15.0	14.0					
Jul 22	21.0	21.0	21.0	21.0	21.0	20.5					
Aug 12	16.5	16.0	16.0	16.0	15.0	15.0					
Aug 25	22.0	22.0	22.0	21.5	21.5	21.5					
Sep 12	20.0	20.0	19.5	19.5	19.5	19.0					
Oct 17	13.0	13.0	13.0	13.0	13.0	13.0					
10m											
Jun 8	18.5	17.0	17.0	16.0	16.0	16.0	16.0	14.5			
Jun 23	17.5	16.0	15.5	15.0	15.0	15.0	15.0	12.5			
Jul 22	21.0	21.0	21.0	20.5	20.5	20.5	20.0	19.0			
Aug 12	19.5	18.0	17.0	17.0	16.5	16.5	16.5	16.0			
Aug 25	22.0	22.0	22.0	21.5	21.5	21.5	21.5	--			
Sep 12	19.5	19.5	19.5	19.5	19.5	19.0	18.5	--			
Oct 10	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0			

*Temperature at the surface, not air temperature

Appendix 1. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
15m											
Jun 8	19.0	17.5	17.0	16.5	16.5	16.0	15.5	13.0	13.0	13.0	
Jun 23	18.0	16.5	16.0	15.5	15.0	15.0	14.5	13.5	12.0	11.0	
Jul 22	21.5	21.5	21.5	21.5	21.0	21.0	20.5	20.0	20.0	19.0	
Aug 12	20.0	19.0	17.5	17.0	17.0	17.0	16.0	16.0	16.0	15.5	
Aug 25	23.0	22.5	22.0	22.0	22.0	22.0	22.0	21.5	--	--	
Oct 10	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
18m											
Jun 8	21.0	18.0	17.0	17.0	16.5	16.5	15.0	14.0	13.0	13.0	13.0
Jun 23	18.0	17.5	16.0	16.0	15.5	15.0	14.5	11.5	11.0	10.5	8.5
Jul 22	21.0	21.0	21.0	21.0	20.5	20.5	20.0	19.5	19.5	19.0	--
Aug 12	20.0	19.0	18.5	17.5	16.5	16.5	16.5	13.0	11.5	10.5	--
Aug 25	23.0	22.0	22.0	22.0	22.0	22.0	21.5	21.5	21.0	10.5	--
Sep 12	20.0	19.5	19.5	19.5	19.5	19.5	19.0	15.5	14.5	14.5	--
Oct 17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5

2. Daytime temperatures (C) in Lake Michigan on the Burns Ditch Transect at [illegible], 10, 15 and 18 m stations by depth in 1970.

Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
	16.5	16.5	16.0	16.0	16.0	16.0					
	24.0	23.0	23.0	22.0	19.0	18.0					
	16.0	16.0	16.0	16.0	16.0	16.0					
	25.0	23.0	23.0	21.5	21.5	--					
	19.5	19.0	17.5	17.0	15.0	15.0					
	15.0	14.5	14.5	14.5	14.5	14.5					
	17.0	17.0	16.0	16.0	16.0	16.0	16.0	16.0			
	23.5	23.0	23.0	23.0	22.0	22.0	17.5	17.0			
	16.0	16.0	15.5	15.5	15.5	15.5	15.5	15.5			
	25.0	25.0	24.0	24.0	24.0	24.0	--	--			
	18.0	18.0	18.0	17.5	17.5	15.5	14.0	13.0			
	15.0	15.0	15.0	14.5	14.5	14.5	14.5	--			

Appendix 3. Daytime temperatures (C) in Lake Michigan on the Gary Transect at 5, 10, 15 and 18m stations by depth in 1970.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
Jul 1	19.0	19.0	19.0	18.5	17.5	17.5					
Jul 31	23.0	23.0	23.0	21.0	20.5	--					
Aug 11	20.5	20.0	19.5	19.5	19.5	--					
Sep 2	21.0	21.0	21.0	21.0	20.5	20.5					
Oct 20	15.0	15.0	15.0	15.0	15.0	15.0					
10m											
Jul 1	20.0	20.0	19.5	19.5	19.0	19.0	18.0	17.0			
Jul 31	23.0	23.0	23.0	22.0	21.5	21.5	21.0	--			
Aug 11	21.5	21.0	20.0	20.0	20.0	20.0	19.5	16.0			
Sep 2	21.0	21.0	21.0	21.0	21.0	21.0	15.5	--			
Oct 20	15.0	14.5	14.5	14.0	14.0	14.0	14.0	--			

Appendix 3. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
15m											
Jul 1	20.0	20.0	20.0	19.5	19.0	19.0	17.0	14.5	13.0	11.5	
Jul 31	23.5	23.0	23.0	23.0	23.0	23.0	18.0	16.5	16.5	--	
Aug 11	21.5	21.5	21.0	20.5	20.0	20.0	20.0	15.0	14.5	14.5	
Sep 2	22.5	22.0	22.0	22.0	22.0	22.0	15.5	13.0	13.0	--	
Oct 20	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.0	14.0	--	
18m											
Jul 31	24.0	23.0	23.0	22.5	22.5	22.5	22.0	19.0	18.0	16.0	--
Sep 2	23.0	23.0	23.0	23.0	22.5	22.5	22.5	11.0	10.0	10.0	--
Oct 20	14.5	14.5	14.5	14.5	14.5	14.5	14.0	14.0	14.0	14.0	--

Appendix 4. Daytime temperatures (C) in Lake Michigan on the Michigan City Transect at 5, 10, 15 and 18 m stations by depth in 1971.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
Jun 2	10.5	10.5	10.5	10.5	10.5	10.5					
Jun 22	20.0	19.0	19.0	18.5	17.5	17.5					
Jul 14	19.5	19.0	19.0	18.5	18.5	18.5					
Jul 30	20.5	20.5	20.5	20.5	20.5	20.5					
Aug 4	15.5	15.0	14.0	14.0	14.0	14.0					
Aug 13	20.0	19.0	19.0	19.0	18.5	18.5					
Aug 30	20.0	20.0	20.0	20.0	20.0	20.0					
Sep 18	20.0	20.0	20.0	20.0	20.0	20.0					
Sep 26	17.0	17.0	17.0	17.0	17.0	17.0					
Oct 23	15.0	15.0	14.5	14.0	12.5	12.5					
Oct 30	15.5	15.5	15.5	15.5	15.5	15.5					

Appendix 4. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
10m											
Jun 2	10.5	10.5	10.5	10.5	10.5	10.5	10.0	10.0			
Jun 23	19.0	18.5	18.5	18.0	18.0	17.5	17.0	17.0			
Jul 14	19.5	19.5	19.5	19.0	19.0	19.0	18.5	18.5			
Jul 30	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5			
Aug 3	20.0	19.5	19.0	18.5	18.0	17.0	15.0	14.5			
Aug 18	19.0	19.0	19.0	18.5	18.0	18.0	18.0	18.0			
Aug 31	20.0	20.0	19.5	19.5	19.5	19.5	19.0	19.0			
Sep 1	20.0	20.0	19.5	19.5	19.5	19.5	19.0	18.0			
Sep 18	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0			
Sep 26	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0			
Oct 2	21.0	20.0	19.0	19.0	19.0	19.0	18.5	16.5			
Oct 30	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5			

Appendix 4. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
15m											
Jun 2	12.0	12.0	11.5	11.5	11.0	11.0	10.0	10.0	10.0	10.0	
Jun 22	19.0	18.0	18.0	18.0	17.5	17.5	17.0	14.0	14.0	14.0	
Jul 14	20.0	19.5	19.5	19.0	19.0	19.0	19.0	18.0	17.5	17.0	
Jul 30	21.0	19.5	19.5	19.5	19.5	19.5	19.0	19.0	17.0	11.0	
Aug 4	15.0	14.5	14.0	13.0	11.5	10.5	10.5	10.5	10.5	10.5	
Aug 18	20.0	19.5	19.0	19.0	19.0	18.0	17.0	13.0	10.0	9.0	
Aug 25	20.0	20.0	20.0	19.5	19.5	19.5	19.5	19.0	18.0	13.0	
Sep 26	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	
Oct 24	15.5	15.0	15.0	15.0	15.0	15.0	15.0	13.5	13.0	12.0	

Appendix 5. Daytime temperatures (C) in Lake Michigan on the Burns Ditch Transect at 5, 10, 15 and 18 m stations by depth in 1971.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
Jun 16	19.0	--	--	--	--	--					
Jul 15	19.5	--	--	--	--	--					
Aug 16	18.5	18.5	18.5	18.5	18.5	18.5					
Oct 3	19.0	19.0	19.0	18.5	16.5	16.0					
Oct 25	16.5	16.0	16.0	16.0	16.0	16.0					
10m											
Jun 16	19.0	--	--	--	--	--	--	--			
Aug 16	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0			
Oct 3	19.5	19.5	19.5	19.0	19.0	16.0	14.0	13.0			
Oct 25	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0			
15m											
Jun 16	20.0	--	--	--	--	--	--	--	--	--	
Aug 16	18.5	18.5	18.5	18.5	18.5	18.5	18.0	18.0	18.0	18.0	
Oct 3	19.0	19.0	19.0	18.5	18.5	18.0	14.0	12.5	12.0	10.5	
Oct 25	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	

Appendix 5. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
18m											
Jun 16	18.0	--	--	--	--	--	--	--	--	--	--
Aug 16	18.5	18.0	18.0	18.0	18.0	18.0	18.0	17.0	10.0	10.0	9.5
Oct 3	19.0	19.0	19.0	19.0	19.0	19.0	19.0	15.5	9.0	7.5	7.5
Oct 25	16.5	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	12.5	12.5

Appendix 6. Daytime temperatures (C) in Lake Michigan on the Gary Transect at 5, 10, 15 and 18m stations by depth in 1971.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
Jun 18	16.5	16.0	16.0	16.0	16.0	16.0					
Jul 18	20.5	20.5	20.0	20.0	20.0	20.0					
Aug 17	19.0	19.0	18.5	18.5	18.5	18.5					
Oct 4	18.0	18.0	18.0	18.0	18.0	18.0					
Oct 25	16.0	16.0	16.0	16.0	16.0	16.0					
10m											
Jun 18	16.5	16.5	16.5	16.5	16.5	16.0	15.5	15.0			
Jul 18	20.5	20.0	20.0	19.5	19.5	19.0	18.5	18.5			
Aug 17	19.0	19.0	18.0	18.0	18.0	18.0	18.0	18.0			
Oct 4	18.0	18.0	18.0	18.0	18.0	18.0	16.5	11.5			
Oct 25	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0			

Appendix 7. Daytime temperatures (C) in Lake Michigan on the Michigan City Transect at 5, 10, 15 and 18 m stations by depth in 1972.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
May 23	13.0	13.0	12.0	10.0	9.0	9.0					
Jun 7	17.0	16.5	15.0	14.5	14.5	14.5					
Jun 27	16.5	15.5	15.0	15.0	14.5	14.5					
Jul 6	18.0	18.0	17.5	17.0	17.0	--					
Jul 13	21.0	20.5	20.5	20.0	20.0	20.0					
Jul 24	25.0	25.0	25.0	25.0	25.0	23.0					
Aug 14	20.0	--	--	--	--	18.0					
Aug 28	23.0	23.0	23.0	23.0	22.0	22.0					
Sep 15	20.0	20.0	20.0	20.0	20.0	20.0					
10m											
Aug 28	23.0	22.5	22.5	22.5	22.5	22.0	22.0	21.0			

Appendix 7. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
15m											
May 23	13.0	12.5	12.0	11.0	11.0	11.0	10.0	9.0	8.5	8.5	
Jun 7	15.5	15.0	15.0	15.0	15.0	14.5	14.0	13.0	13.0	12.5	
Jun 27	17.5	16.5	16.0	15.0	14.5	14.5	14.0	13.5	13.5	13.5	
Jul 6	18.5	17.5	16.5	16.5	16.0	16.0	16.0	16.0	16.0	15.5	
Jul 13	23.0	20.5	20.0	20.0	20.0	20.0	20.0	19.5	19.0	13.0	
Jul 24	25.0	25.0	25.0	24.5	24.5	24.5	24.5	15.5	11.5	9.5	
Aug 14	20.5	--	--	--	--	--	--	--	--	16.0	
Aug 28	22.0	22.0	21.5	21.5	21.5	21.5	21.0	21.0	21.0	18.0	
Sep 15	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	
18m											
Aug 28	22.0	22.0	21.5	21.5	21.5	21.5	21.5	21.5	21.0	16.0	11.0

Appendix 8. Nighttime temperatures (C) in Lake Michigan on the Michigan City Transect at 5 and 10 m stations by depth in 1971.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
Jul 27	22.0	22.0	21.5	21.5	21.5	21.5					
Aug 13	19.0	19.0	19.0	19.0	19.0	19.0					
Aug 31	20.5	20.5	20.0	20.0	20.0	20.0					
Sep 26	17.0	17.0	17.0	17.0	17.0	17.0					
Oct 23	16.5	16.5	16.5	16.5	16.5	16.5					
10m											
Jun 3	13.0	12.0	12.0	12.0	12.0	11.5	11.0	11.0			
Jun 23	20.0	19.5	19.0	19.0	18.5	18.5	18.0	17.0			
Jul 17	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0			
Aug 3	20.0	20.0	20.0	20.0	19.5	19.0	19.0	18.5			
Aug 17	19.0	18.5	18.0	18.0	17.5	17.5	17.5	17.5			
Sep 1	19.5	19.5	19.5	19.0	19.0	18.5	18.0	18.0			
Oct 2	19.5	19.0	19.0	18.5	18.5	18.5	18.5	14.0			
Oct 30	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.0			

Appendix 9. Nighttime temperatures (C) in Lake Michigan on the Michigan City Transect at 5, 10, 15 and 18 m stations by depth in 1972.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
5m											
May 23	11.0	11.0	10.5	10.0	10.0	10.0					
Jun 8	15.0	15.0	15.0	14.5	14.5	14.5					
Jun 26	16.0	15.0	15.0	15.0	14.5	14.5					
Jul 5	17.5	16.5	16.5	16.5	16.5	16.5					
Jul 13	22.0	21.5	20.5	20.5	20.5	20.5					
Jul 24	25.0	25.0	25.0	25.0	25.0	23.5					
Aug 13	20.0	19.5	19.0	19.0	18.5	18.0					
Aug 29	22.0	22.0	22.0	22.0	22.0	22.0					
Sep 16	19.5	19.5	19.5	19.5	19.5	19.5					
10m											
Jul 5	17.0	17.0	16.5	16.0	16.0	16.0	16.0	16.0			

Appendix 9. cont.

Station / Date	Depth (m) 0	1	2	3	4	5	7	10	12	15	18
15m											
May 23	11.0	11.0	10.0	10.0	9.0	9.0	8.0	8.0	8.0	8.0	
Jun 8	15.5	15.5	15.0	15.0	15.0	15.0	14.5	14.0	14.0	13.5	
Jun 27	16.0	15.5	15.0	15.0	15.0	15.0	14.5	14.0	14.0	14.0	
Jul 5	16.5	16.5	16.5	16.0	16.0	16.0	16.0	16.0	16.0	15.5	
Jul 13	21.5	21.0	21.0	21.0	20.5	20.0	20.0	19.5	19.5	13.0	
Jul 24	25.0	25.0	25.0	25.0	25.0	25.0	25.0	14.0	11.0	9.5	
Aug 13	21.0	20.5	19.0	18.0	17.5	17.5	17.5	17.0	17.0	17.0	
Aug 29	22.0	22.0	22.0	22.0	22.0	22.0	21.0	21.0	21.0	20.0	
Sep 16	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	
18m											
Jul 5	16.5	16.5	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.0	15.0

Appendix 10. Secchi disc visibility (ft) by station in Lake Michigan at the Michigan City Transect at 5, 10, 15 and 18 m stations in 1970, 1971 and 1972.

Year / Date	Station 5m	10m	15m	18m
1970				
Jun 8	4.0	5.0	6.0	7.5
Jun 23	8.0	11.0	14.5	16.0
Jul 22	2.0	2.0	2.0	2.0
Aug 12	10.0	10.0	10.0	12.5
Aug 25	6.0	11.0	11.0	12.0
Sep 12	4.5	5.0	--	5.0
Oct 17	3.0	3.5	3.5	6.0

Appendix 10. cont.

Year / Date	Station 5m	10m	15m	18m
1971				
Apr 22	2.0	3.0	4.0	6.5
Jun 2	9.5	11.5	15.0	16.0
Jun 22	9.0	11.0	15.0	--
Jul 14	8.5	8.5	10.5	25.0
Jul 30	13.0	19.0	20.0	26.0
Aug 4	10.0	10.0	10.5	10.5
Aug 18	15.0	16.0	14.0	15.0
Aug 31	10.0	14.5	15.5	15.0
Sep 1	--	14.0	--	--
Sep 18	6.0	7.0	--	--
Sep 26	9.0	9.0	10.0	10.0
Oct 2	--	15.5	--	--
Oct 24	6.5	11.5	12.0	12.0

Appendix 10. cont.

Year / Date	Station 5m	10m	15m	18m
1972				
May 23	11.0	--	11.0	--
Jun 7	5.5	--	17.0	--
Jun 27	7.5	--	9.5	--
Jul 6	11.0	--	13.5	--
Jul 13	12.5	--	13.0	-
Jul 24	10.5	--	8.5	--
Aug 14	10.0	--	11.0	--
Aug 28	14.5	15.0	22.0	25.5
Sep 15	5.0	--	9.0	--

Appendix 11. Secchi disc visibility (ft) by station in Lake Michigan at the Burns Ditch Transect at 5, 10, 15 and 18 m stations in 1970 and 1971.

Year / Date	Station 5m	10m	15m	18m
1970				
Jun 22	5.0	5.5	5.5	14.0
Jul 28	3.0	3.5	5.0	9.0
Aug 10	4.5	5.0	5.0	10.0
Aug 26	1.5	10.0	11.0	12.0
Sep 12	1.5	3.5	5.0	--
Oct 19	5.0	6.0	6.5	13.0
1971				
Jun 16	8.0	8.0	--	13.0
Jul 15	3.5	10.5	--	27.0
Aug 16	5.5	19.0	20.0	24.0
Oct 3	2.5	7.5	12.0	--
Oct 25	2.5	12.5	16.0	19.0

Appendix 12. Secchi disc visibility (ft) by station in Lake Michigan at the Gary Transect at 5, 10, 15 and 18 m stations in 1970 and 1971.

Year / Date	Station 5m	10m	15m	18m
1970				
Jul 1	7.0	7.5	11.0	--
Jul 31	6.0	10.0	8.5	10.5
Aug 11	7.0	8.0	10.0	--
Sep 2	4.0	5.0	6.0	6.5
Oct 20	7.0	7.0	8.0	9.0
1971				
Jun 18	12.0	15.0	14.0	30.0
Jul 18	12.0	12.0	15.0	--
Aug 17	12.0	13.0	20.0	--
Oct 4	13.5	12.0	15.5	--
Oct 25	10.5	9.0	13.5	--